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Commercial and subsistence harvests of bowhead whales (*Balaena mysticetus*) in eastern Canada and West Greenland

Chasse commerciale et de subsistance à la baleine boréale (*Balaena mysticetus*) dans l'est de l'Arctique canadien et l'ouest du Groenland

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ABSTRACT

Commercial harvesting of bowhead whales (*Balaena mysticetus*) in eastern Canada and West Greenland has a long history, starting with Basque whalers in the Strait of Belle Isle ca. 1530 AD. In the late 1600s Dutch, Danish and German whalers began voyaging to Davis Strait, although data are only available after 1719. Danish-Norwegian colonization of West Greenland started in 1721, and these settlers were also active in bowhead whaling. British whalers were in Davis Strait by the mid-1700s and crossed into Baffin Bay in the early 1800s, starting another pulse in bowhead whaling off Baffin Island, in Lancaster Sound, Prince Regent Inlet and the Gulf of Boothia. American whalers were active in Davis Strait in the 1700s and again in the 1800s, and in Hudson Bay after 1860, where they were joined by Scottish whalers. Smaller numbers of whales were taken by other nations, including France. The last commercial whaling for bowheads in the Canadian Arctic was in 1915, when the population was at extremely low numbers and voyages were no longer profitable. The total commercial harvest from 1530-1915 AD was estimated at 57,507-68,736 whales, with highest harvests by the Basques and British.

Inuit in Canada and West Greenland have hunted bowheads for subsistence, and for trade with Euroamericans, for centuries. Small numbers of whales were taken during the 1900s, and there is currently a limited hunt in Nunavut with similar hunts planned in Nunavik and West Greenland. The first culture to be active bowhead whalers was the Thule, which replaced the Dorset culture in the eastern Arctic ca. 1000 AD. There was significant variation in Inuit dependence on bowhead whales, in both time and space, with important bowhead whaling regions including Disko Bay, Cumberland Sound and Somerset Island. The harvest before commercial whaling began (1000-1529 AD) was estimated at ca. 15,000 whales, with a maximum yearly harvest of 36 whales. This was based on the abundance of whale bone at winter houses excavated by archaeologists. After 1500 AD bowhead whaling declined, possibly related to changing climatic conditions, a reduced whale population from Basque harvests, or a combination of both factors. The total estimated harvest between 1530 AD and the end of commercial whaling was 8,460 whales. Inuit whaling declined again after commercial whalers overharvested the bowhead population, and only 56 whales are known to have been harvested (or struck and lost) after 1918. The estimated Inuit harvest is based on scattered data and a number of assumptions. There is some evidence that at least parts of the harvest series are underestimates. Even if harvests were higher they would likely not have been large enough to cause population declines. The long tradition of Inuit bowhead whaling was negatively impacted by commercial harvests.

Combining the commercial and Inuit harvests after 1530 AD results in a total estimated kill of over 70,000 whales (not including struck and lost and known to be incomplete for some nations and eras). Nearly all (ca. 88%) were taken by Euroamerican commercial whalers. While still incomplete, the harvest series is more detailed than previously available data and should improve modelling efforts to estimate pre-whaling population size. However, any modelling should rigorously assess the sensitivity of the results to varying aspects of the harvest series due to the number of assumptions included. The quality of the harvest data varies considerably by nation and era, and the different series were assigned to a 3-point scale for data reliability. Over half the estimated total harvest is considered to be the least reliable, including Basque harvests and most Inuit harvests. Population modelling studies will need to explicitly incorporate this variability in data quality.

RÉSUMÉ

La longue histoire de la chasse commerciale à la baleine boréale (*Balaena mysticetus*) dans l'est du Canada et l'ouest du Groenland débute vers 1530 avec la venue des baleiniers basques dans le détroit de Belle-Isle. À la fin des années 1600, les baleiniers hollandais, danois et allemands ont effectué leurs premiers voyages dans le détroit de Davis, mais les données ne sont disponibles qu'à partir de 1719. Les colons danois et norvégiens, arrivés dans l'ouest du Groenland en 1721, participaient aussi activement à la chasse à la baleine boréale. Les baleiniers britanniques exploitaient les eaux du détroit de Davis au milieu des années 1700 et sont allés dans la baie de Baffin au début des années 1800, donnant une nouvelle impulsion à cette chasse au large de l'île de Baffin, dans le détroit de Lancaster, l'inlet Prince-Régent et le golfe de Boothia. Les baleiniers américains étaient actifs dans le détroit de Davis dans les années 1700 et 1800, de même que dans la baie d'Hudson après 1860, où les baleiniers écossais se sont joints à eux. Des prises moindres ont été réalisées par d'autres nations, dont la France. La chasse commerciale à la baleine boréale dans l'Arctique canadien a pris fin en 1915, la population ayant atteint des effectifs extrêmement faibles et les voyages n'étant plus profitables. Les prélèvements commerciaux de 1530 à 1915 se sont situés, selon les estimations, entre 57 507 et 68 736 baleines, les prises les plus élevées ayant été réalisées par les Basques et les Britanniques.

Les Inuits du Canada et de l'ouest du Groenland chassent la baleine pour assurer leur subsistance et pour commercer avec les Euro américains depuis des siècles. Peu de baleines ont été prises durant les années 1900, et la chasse est actuellement limitée au Nunavut; il en sera de même au Nunavik et dans l'ouest du Groenland. La première culture à donner naissance à des chasseurs actifs fut la culture de Thulé, qui a remplacée la culture Dorset dans l'est de l'Arctique vers l'an 1000. La dépendance des Inuits à la baleine boréale a varié considérablement tant dans l'espace que dans le temps. Parmi les régions où la chasse ciblant cette espèce était importante, citons la baie de Disko, la baie Cumberland et l'île Somerset. Les prélèvements antérieurs aux débuts de la chasse commerciale à la baleine (de 1000 à 1529) ont été estimés à environ 15 000 baleines, les prises annuelles maximales s'établissant à 36 baleines. Ces chiffres reposent sur l'abondance des ossements de baleines trouvés dans des maisons d'hiver excavées par des archéologues. Après l'an 1500, la chasse à la baleine boréale a décliné, peut-être en raison des conditions climatiques changeantes, d'une raréfaction des baleines attribuable aux prélèvements basques ou d'une combinaison de ces deux facteurs. Les prélèvements totaux entre l'an 1530 et la fin de la chasse commerciale sont estimés à 8460 baleines. La chasse par les Inuits a décliné de nouveau après que des baleiniers commerciaux aient surexploité la population de baleines boréales, et seulement 56 baleines auraient été prélevées (ou abattues et perdues) après 1918. L'estimation des prélèvements inuits repose sur des données éparses et un certain nombre d'hypothèses. Certaines preuves attestent qu'au moins une partie de la série de données sur les prélèvements est sous-estimée. Même si les prélèvements avaient été supérieurs, ils n'auraient vraisemblablement pu être suffisamment élevés pour causer des déclins de la population. Ainsi, la longue tradition de la chasse à la baleine boréale par les Inuits a subi les effets négatifs de la chasse commerciale.

Les prises totales estimées, en combinant les prélèvements commerciaux et inuits après l'an 1530 mais n'incluant pas les animaux abattus et perdus et reconnues comme étant incomplètes pour certaines nations et certaines époques, atteignent plus de 70 000 baleines. La quasi-totalité de ces prises (environ 88 %) est l'œuvre des baleiniers

commerciaux euro-américains. Bien qu'encore incomplète, la série sur les prélèvements contient des données plus détaillées que celles disponibles par le passé et devrait nous permettre d'améliorer la modélisation afin d'estimer l'effectif de la population avant la chasse. Cependant, toute modélisation doit évaluer rigoureusement la sensibilité des résultats aux aspects variables de la série sur les prélèvements en raison du nombre d'hypothèses incluses. La qualité des données sur les prélèvements varie considérablement d'une nation et d'une époque à l'autre, c'est pourquoi chaque série a reçu une cote sur une échelle de trois points pour la fiabilité des données. Plus de moitié des prélèvements estimés sont considérée comme moins fiables, y compris les prélèvements des Basques et la plupart des prélèvements des Inuits. Les études de modélisation de la population devront incorporer de façon explicite cette variabilité de la qualité de données.

INTRODUCTION

The bowhead or Greenland right whale (*Balaena mysticetus*), found in circumpolar waters, is the most northerly distributed baleen whale. Both it and the closely-related North Atlantic right whale (*Eubalaena glacialis*) were long considered the "right" whales to hunt, and the commercial harvests series of these species are the longest of all cetaceans. COSEWIC considers two eastern populations (Davis Strait-Baffin Bay and Hudson Bay-Foxe Basin), both of which are 'Threatened' (COSEWIC 2005). However recent genetic and satellite tagging data (Dueck et al. 2006; Heide-Jørgensen et al. 2003, 2006; Postma et al. 2006) indicates that the bowhead whales in eastern Canada and West Greenland constitute a single population with considerable age and sex structuring. COSEWIC is currently reassessing the status of bowhead whales in eastern Arctic given the new information on stock structure (and also abundance). The population supports a limited subsistence hunt by Nunavut Inuit, with hunts by both Nunavik and West Greenland Inuit planned for the near future.

Subsistence bowhead whaling by Thule Inuit in the central and eastern Arctic started ca. 1000 AD, and commercial harvests started with Basque whalers ca. 1530 AD and ended with American and Scottish whalers in Hudson Bay in the early 1900s. This report summarizes the available harvest data for bowhead whales in the waters of eastern Canada and West Greenland. These data are mostly from published sources. Archived sources in museums will undoubtedly provide further information; however such diligent research is beyond the scope of this report.

The catch series is being summarized for use with population models to "back-calculate" a population trajectory and estimate pre-exploitation population levels. These estimates will allow the setting of population recovery targets. There have been several past attempts to estimate pre-whaling population size (reviewed by Woodby and Botkin 1993). Mitchell (1977) used a three-step method that involved summing the number of whales killed during the peak decade, correcting upwards for struck and lost whales, and estimating the residual population after the peak decade, based on the number of whales harvested in following decades. Using this method Mitchell (1977) estimated the Davis Strait "stock" to be about 6000 whales in 1729 and the Hudson Bay "stock" about 680 in 1859. The Davis Strait estimate was subsequently revised to 11000 in 1825 (Mitchell and Reeves 1981). Woodby and Botkin (1993) used a simple population model and estimated similar pre-exploitation population sizes. These estimates were all based on limited harvest data, and more complete data will provide better estimates.

A number of different nations harvested bowhead, but the harvest series is far from complete and the availability of harvest records varies considerably between nations and eras. There are a number of limitations associated with the available data on commercial bowhead whaling (see Ross 1979a, b). There are a number of problems with many whaling sources, for example, see Schevill (1957) on Sanderson (1956) ("an irresponsible book... Ivan Sanderson's carelessness is evident..."), Barkham (1994) on Proulx (1993), and Sanger (1985) on Jenkins (1971) and Jackson (1985) (which, despite being one of the best sources on British whaling, still contains a number of errors). Ultimately, nearly all sources and most major commentaries are flawed to some extent (Sanger, pers. comm. in Higdon 2008).

A number of different Native cultures have inhabited the Canadian eastern Arctic and West Greenland (McGhee 1990; Stoker and Krupnik 1993). The Thule, the first culture to

be active bowhead whalers, migrated eastward from Alaska ca. 1000 AD (Savelle and McCartney 1990). Inuit in West Greenland and eastern Canada traditionally used bowhead whales for subsistence, and whale bones were used in the construction of winter houses (Kaplan 1985; Savelle and McCartney 1990; Taylor 1988). Blubber and baleen were also traded to Euroamerican whalers and traders. Inuit harvests themselves likely never had significant negative effects on bowhead population size, given small populations of hunters and selection for young whales (McCartney and Savelle 1985, 1993; Savelle and McCartney 1991, 1994). However, when taken in concert with commercial whaling after ca. 1530, subsistence removals may have had a cumulative effect on population size and should therefore be included in any harvest series. There is little documentation of Inuit harvests, and no harvest series exists.

Research on the Thule and historic Inuit cultures have seldom been designed to examine whaling, but rather have been site-specific studies designed around cultural-historic questions (Savelle and McCartney 1990). This makes it difficult to quantify the importance of bowhead whales to the classic Thule, modified Thule and historic Inuit cultures. For the purposes of reconstructing harvests to estimate pre-commercial exploitation population size, kills during the classic Thule phase (the peak of aboriginal bowhead whaling, occurring prior to commercial exploitation) are not relevant. However, knowledge of the importance of bowhead whales to the early Thule adds context to the estimates of harvests after 1530 AD.

The harvest data are summarized by nation and divided into two broad sections – Euroamerican and Inuit subsistence whaling. The first European bowhead whalers were Norse settlers in West Greenland from 986 until ca. 1500 AD (Jones 1986). The settlers used whales for subsistence purposes (Degerbøl 1936; McGovern et al. 1996; Enghoff 2003), but the number harvested is not known. However it was likely minor and occurred prior to the establishment of commercial whaling, and no harvest is included here. Commercial efforts of all nations were influenced by numerous political, social and economic factors that are beyond the scope of this review. A number of sources are available, including Jackson (1978), Ross (1993) and Scoresby (1820).

EUROAMERICAN WHALING

Commercial whaling grounds

Commercial bowhead whaling in eastern Canada and West Greenland occurred on a number of different "grounds" (see summaries by Reeves et al. 1983; Ross 1993). The geographical distribution of whaling was related to whale abundance but also changed in response to numerous socioeconomic and political factors (Ross 1993). Nineteenth-century whalers had a detailed knowledge of bowhead distribution and migration patterns, and this knowledge allowed the fleets to establish itineraries for catching whales at different seasons and at different areas (Reeves et al. 1983). The seven main grounds are shown in Figure 1.

The first bowhead whaling ground in the western North Atlantic, the Strait of Belle Isle/Gulf of St. Lawrence area ("Grand Bay"), was started by the Basques in 1530 and already in decline by the late 1500s (Barkham 1984). An international fishery for bowheads on grounds all along the West Greenland coast (to ca. 73° North) was started by the Dutch and Germans in the late 1600s (although no data are available until 1719) (de Jong 1978, 1983; Ross 1979a). Shore-stations were established by Danish colonists in the early

1700s, but most whales were taken in a spring and summer pelagic fishery centered on grounds near the West Greenland coast (Reeves et al. 1983). This included much of the Davis Strait whaling conducted by the Dutch, Germans and British (particularly prior to 1817 when the western Baffin Bay fishery started). Many important grounds on the "east side" were depleted by the early 1800s (Reeves et al. 1983).

The "south-west fishing" grounds, centered on the pack ice edge in the Resolution Island area, were an alternative to the West Greenland ("east side") grounds in the spring. The fishery occurred at the mouth of Hudson Strait, along the southeast coast of Baffin Island to Cumberland Sound, and along the northeast coast of Labrador (Reeves et al. 1983). This was among the most difficult aspect of the fishery (Scoresby 1820, Vol. 2), where large numbers of whales were seen but were hard to catch because of the weather and the ice (Gray 1888). The fishery could start as early as April and often lasted through June (Reeves et al. 1983), with whales sometimes still caught as late as July in icy conditions near the Labrador coast (Scoresby 1820 Vol. 2).

The "west water" was a summer fishery conducted in the vicinity of Pond Inlet, the Lancaster Sound region, Prince Regent Inlet and the northern Gulf of Boothia. The fishery started in 1827 when Scottish vessels first penetrated the Melville Bay ice and crossed Baffin Bay (Ross 1979a, 1993). Large whales were often present off the mouth of Pond Inlet (Smith 1922) and most summer catches were made here from early June to early September (Low 1906; Brown 1868). A number of authors wrote about the abundance of whales in Prince Regent Inlet and the northern Gulf of Boothia during July, August and early September (reviewed by Reeves et al. 1983). Some years were "closed seasons", in which the land-floe persisted in western Baffin Bay and blocked the entrances to Pond Inlet and Lancaster Sound. Large numbers of whales would aggregate along the land-floe when their westward migration was blocked; and harvests were often high but comprised of small (young) whales (Lubbock 1937; Reeves et al. 1983; Finley and Darling 1990).

The autumn "rock-nosing" grounds were found along almost the entire east coast of Baffin Island. This was an inshore fishery undertaken by vessels that failed to fill their holds at the "south-west fishing" or "west water" grounds (Reeves et al. 1983). Vessels would leave the Lancaster Sound area in late August or early September, and some would remain on the grounds until November, by this time they would be rock-nosing in Cumberland Sound or south. In the late 1800s Cumberland Sound also became an important ground for early and late-season whaling, often using shore-stations and with some overwintering (Ross 1979a, 1993; Sanger 2008 in press). The last ground opened was northwest Hudson Bay, which had a short lifespan (1860-1915). American and Scottish vessels arrived in mid-August, whaled for a month before finding a winter harbour, and then started spring floe-edge whaling from whaleboats in May (Ross 1974, 1979).

Basque whalers

The Basque first started whaling in the eastern Atlantic (Bay of Biscay) before moving to the northwest Atlantic. Basque whalers became established in the Strait of Belle Isle ca. 1530 AD and were there on an annual basis until ca. 1630 (Aguilar 1986; Barkham 1977, 1978, 1984; Cumbaa 1986). The fishery peaked in the mid 1500s (the most productive decades were the 1560s and 1570s) and was in decline by the 1580s, with some ships returning half-empty (Aguilar 1986; Barkham 1984). Basque effort greatly diminished after ca. 1590, and the north shore of the Strait of Belle Isle was abandoned by the early 1630s (Barkham 1984). It was not until ca. 1580 that the whalers extended their grounds west

into the Gulf of St. Lawrence, an expansion that occurred after the peak whaling efforts (Barkham 1978; McLeod et al. 2008).

Basque whaling in Newfoundland and the Gulf of St. Lawrence officially ended in 1713 with the signing of the Treaty of Utrecht, although the industry had been in decline long before this time. Most of the 20 known whaling stations were abandoned by the mid-1600s, but at least one station (Petit Mécatina, QC) was active into the early 1700s (McLeod et al. 2008). Overhunting was one potential cause of whaling decline, but other factors such as conflict with local aboriginal peoples, rising taxes, alternative economic pursuits like cod fishing, and impressments of whaleships into naval service all played a role (reviewed by Ross 1993). The opening of the Spitsbergen fishery in the early 1600s, with its large and unexploited whale stocks, was undoubtedly a major factor in the decline of Grand Bay whaling. Both English and Dutch vessels in Spitsbergen hired Basque whalers (de Jong 1978, 1983; Jenkins 1971). Scattered Basque vessels were also reportedly in Davis Strait (off Disko Bay) in the mid 1730s (Gad 1972).

Several authors have estimated the typical catch per year during the peak of Basque whaling. Using 12 whales per vessel and 20-30 vessels per year, Aguilar (1986) estimated a total yearly harvest of 300-500 whales (not including those struck and lost) and suggested that 25,000-40,000 whales were killed during the peak period of ca. 1530-1610. Barkham (1984) used 15 ships per year (but acknowledged that there were likely at least 20 ships during the peak years), and an average capacity of 1,000 barrels per ship to estimate peak yields of 300 whales per year. Aguilar's (1986) Figure 4 provides the most objective measure of Basque whaling effort, based on the number of extant manuscripts or written references as an index of activity. However this must be used with caution as the relative abundance of documents is not necessary correlated with whaling intensity. The number of documents written before 1530 was negligible (ca. 3%). Assuming 12 whales per ship (Aguilar 1986), Table 1 shows estimated Basque harvests from 1530-1713, using a range of peak vessel numbers and assuming the distribution of written records is representative of effort.

The proportion of written references (Aguilar 1986) peaks from the 1550s to the 1570s, agreeing well with the peak in whaling activity as reported by Barkham (1984). Assuming 12 whales per vessel, 25 vessels per year during the peak of Basque whaling effort equates to an average of 300 whales per year during the peak period. Vessel estimates of 20 and 30 result in yearly peak harvests of 260 or 360 whales per year, respectively. These values agree well with the estimates by Aguilar (1986) and Barkham (1984).

Historical research has shown that there were two distinct Basque whaling periods, the summer season in June/July and the winter whaling season. During the early years of Basque whaling the vessels generally returned to Europe after the summer season, but in the 1550s the whalers discovered an influx of whales that arrived in September/October, and they then started staying for the winter whaling season (Huxley [Barkham] 1987 in McLeod et al. 2008). The two seasons were typically interpreted as a right whale hunt in the summer and a bowhead hunt during the winter (Aguilar 1986; Cumbaa 1986). However given that the harvest was nearly all bowhead whales (see below), the distinct summer and winter whaling seasons likely represented sex- and/or age-based segregation and migration of the bowhead population (McLeod et al. 2008). The summer seasonal hunt was largely abandoned by the mid-1570s (McLeod et al. 2008).

The *San Juan* sank in Red Bay, Labrador in autumn 1565 and was discovered in the late 1970s (Barkham and Grenier 1978). Excavation led to the recovery of a number of bones of whales that the Basques harvested in the 1500s (Barkham 1984). Cumbaa (1986) examined humeri of 17 individuals, and osteological analysis suggested nine bowhead and eight right whales. However recent genetic analyses of these same bones have shown that the harvest was actually nearly all bowhead. Rastogi et al. (2004) analysed 21 humeri that had been identified using osteological analyses as eight bowheads and 13 right whales. DNA analysis identified only one as a right whale and the remaining 20 as bowhead. The bones were from a minimum of 16 individuals – for a harvest that was ca. 94% bowhead. McLeod et al. (2006) present preliminary results of more extensive analyses than that of Rastogi et al. (2004). Analyses of 188 bones from 18 different sites indicate that 183 are from bowhead whales, one is from a right whale, and four are from other species (Frasier et al. 2007, in McLeod et al. 2006). Additional genetic analyses have since been conducted on 218 bone samples, from 10 different sites (McLeod et al. 2008 in press). Five different species were present, and 203 of these bones (93%) were from bowhead whales. The 218 bones were from a minimum of 80 individuals, and 72 of these were bowheads (90%).

There is thus considerable evidence that the vast majority (≥ 90%) of Basque harvests were bowhead whales. Assuming a peak of 25 vessels (the midpoint of Table 1, also see Aguilar 1986), 31,182 whales might have been harvested from 1530-1713, of which an estimated 28,075 were bowheads (assuming 90% of the total harvests). Assumed peak vessel numbers of 20 and 30 result in an estimated bowhead harvest of 22,454 and 33,683, respectively.

Aguilar (1986) suggested that 25,000-40,000 whales were taken from 1530-1610. In this study the harvests during this peak period are lower, with 67% of the total taken prior to 1610 (20,930 whales, 18,846 of which were bowheads). The proportion of written references per 25-year period declined after 1551-1575, which agrees with other author's suggestions of the peak of Basque whaling effort (Barkham 1984). However it increased again after 1651, even though Basque whaling had declined considerably by this time and most whaling stations had been abandoned (McLeod et al. 2008). Much of the available written documentation may have been in reference to past whaling activities and may thus not be completely representative of Basque whaling effort.

Dutch whaling

Dutch whaling in Davis Strait started in the 1600s as an extension of their dominance on the Spitsbergen grounds. However harvest data are only available after 1719, when the trade became considerable enough to be distinguished from the trade which occurred east of Greenland (de Jong 1978, 1983). In Davis Strait the number of Dutch vessels peaked in 1732 (Vaughn, 1986). After this time numbers fluctuated, with a near-continuous decline after 1770 (de Jong 1978). de Jong (1978, 1983) and Ross (1979a) provide statistics on the number of vessels sailed and the number of whales flensed for the Davis Strait fishery. Ross (1979a) notes 3,329 voyages catching 7,644 whales from 1719-1826. de Jong's (1978, 1983) numbers are slightly higher, showing 3,348 Dutch vessels capturing 7,697 whales from 1719- 1823. The harvest series used here is based on the source with the highest number of whales caught, with yearly gaps filled in from other sources where appropriate. de Jong (1978, 1983) includes more harvests than Ross (1979a), but Ross (1979a) contains catch information for 1802 and 1824-1826, not included by de Jong (1978, 1983). Ross' (1979a) catches for these years were added to the de Jong (1978,

1993) series for a total Dutch catch of 7,699 whales from 1719-1826. This is an incomplete series and thus an underestimate, as Dutch traders and whalers were in West Greenland starting in the late 1600s (Kuup and Hart 1976) but no data are available.

British whaling

Both England and Scotland have a long history of Arctic whaling. In the early 1600s the English competed fiercely with the Dutch in the Spitsbergen fishery (Conway 1904, 1906; de Jong 1978, 1993; Ross 1993). The Dutch eventually dominated and the English fleet essentially gave up whaling, returning in the 1700s after Davis Strait whaling had started. It is not possible to conclusively determine when the English first started Davis Strait whaling (Vaughn 1986) but it was likely ca. 1750 when the British government increased the bounty for whaling vessels (Jackson 1978; Ross 1979a, 1993). British whaling began to increase significantly in the 1770s as the Dutch fleet declined (Vaughn 1986; Ross 1993). In 1817 two Scottish vessels crossed to Baffin Island and caught a large number of whales, which led to the development of a new British fishery in Lancaster Sound and along the Baffin Island coast, involving a counter-clockwise circuit of Baffin Bay (Dunbar 1972; Vaughn 1986, 1991; Ross 1979a, 1993). By the second half of the 19th century the industry was dying, and only the Scots continued to outfit vessels. Scottish whalers continued to be successful because they expanded their harvest to other species such as beluga whales (*Delphinapterus leucas*) and seals and pioneered the use of steam-powered vessels (Jackson 1978; Sanger 1985).

Sanger (1985) presents harvest statistics for both Davis Strait and east of Greenland for 1750-1801, but for Scottish vessels only. In Davis Strait 84 Scottish vessels caught 301 whales. Ross (1979a, 1993) presents British whaling data from 1814 onwards, using a variety of sources including whaling logbooks and the "Kinnes Lists", a nearly continuous shipping list giving the particulars of whaling voyages, in the possession of the Dundee firm of Robert Kinnes & Sons. The Kinnes Lists begin in 1790 and end in 1911, but do not separate Davis Strait catches until 1814. Ross (1979a) included 20,043 whales harvested by 2,600 vessels ("ship-seasons") from 1814-1911. Ross (1979a) was careful to note the provisional nature of his harvest series and that additional research was required. In addition, Ross (1979a) did not include the sources (i.e., logbooks and journals) that he used, thus making it difficult to judge the quality of the research.

Dr. Chesley Sanger (Memorial University of Newfoundland, St. John's, NL) has provided unpublished data collected during his PhD research (Sanger 1985) that improves the harvest series of Ross (1979a). Sanger (unpublished) includes Scottish harvests from 1751-1813 (1,519 whales, which includes the 1750-1801 data from Sanger 1985), and both Scottish and English harvests from 1814-1910. Sanger (unpublished) used the same Kinnes Lists as Ross (1979a) however this was updated using other sources (mainly newspapers), particularly for the Scottish aspect of the fishery. Sanger (unpublished) provides a total British harvest of 20,308 whales (12,111 by Scottish and 8,197 by English) secured by 2,607 vessels (1,659 Scottish and 948 English) from 1814-1910. This is a slight increase for the number of vessels and whales in Ross (1979a). The biggest difference between the two series is Sanger's inclusion of Scottish catches from land-station catches in Cumberland Sound, which Ross (1979a, b) noted were missing from his compilation. From 1853-1890 a minimum of 68 overwintering Scottish voyages secured at least 346 whales (Sanger 2008 in press). The harvest series here therefore uses Sanger (unpublished) as the main source for British whaling till 1910, with harvests for 1911 from Ross (1979a), resulting in a total British harvest of 20,312 whales.

None of the aforementioned sources provide English data prior to 1814, with the exception of six whales harvested by the Hudson Bay Company from 1767-1772 (Ross 1974, 1979a). However Jackson (1978) provides some limited information to help fill gaps for early English whaling: the number of English vessels from 1733-1785; the number of Scottish vessels from 1750-1785; yearly average oil and bone returns for 1733-1795; and the number of English and Scottish vessels clearing to, and entering from, "Greenland" for 1781-1800. Jackson (1978) does not distinguish between whaling east and west of Greenland, but Sanger (1985) does for the number of Scottish vessels sailed, and whales harvested, from 1750 to 1801.

Here I assume that the English started whaling in Davis Strait whaling in 1750 (Jackson 1978; Ross 1979a, 1993). This is the first year Scottish whaling data, separated into the two grounds, are available (Sanger 1985; in 1750 there was only one Scottish vessel, which fished east of Greenland). Between 1733 and 1749 the number of English Greenland vessels ranged from 3-6 (Jackson 1978). If there was any British activity in Davis Strait prior to 1750, as suggested by Jenkins (1971) and Gad (1973), it was likely of minor importance. Scottish whalers were in Davis Strait from 1751-1754, then moved all their effort to East Greenland, not returning to Davis Strait again until 1787 (Sanger 1985). From 1787-1814 the catch between the two grounds fluctuated, in some years more whales were harvested east of Greenland, in others the majority were taken in Davis Strait (Sanger unpublished).

The oil returns in Jackson (1978) for 1750 onwards were converted to number of whales using six barrels to one ton (Jenkins 1971) and 85 barrels per whale (Aguilar 1986). The number of whales harvested by English vessels was determined by subtracting the Scottish northern whale harvest from both grounds (Sanger 1985, unpublished). The proportion of Scottish vessels and whale harvests in Davis Strait (Sanger 1985) was then used to estimate the proportion of total English vessels and whales (from Jackson 1978) that were in Davis Strait. This resulted in an estimate of 1,298 whales captured by 414 vessels (Table 2). When combined with Sanger's (1985, unpublished) Scottish data, the total British harvest prior to the establishment of the Kinnes Lists in 1814 was estimated as 2,817 whales, with the majority (1,519) caught by the Scots, and most of these (1,245) taken from 1801 to 1813 (Sanger, unpublished). Ross (1979a) estimated that there were over 400 British voyages to Davis Strait prior to 1814, and the estimated number of voyages here (414 English plus 84 Scottish) agrees well with this. There may have been additional voyages, for example from 1801-1813, and also during the 1755-1786 period when the Scots fished east of Greenland only (Jackson 1978; Sanger 1985).

Estimating the English harvest in this manner assumes that Scottish and English vessels were equal in their distribution on the two grounds, which may not be the case. In 1750 there was one Scottish vessel, which fished on the East Greenland grounds (Sanger 1985), so in this estimate none of the 19 English vessels were assigned to Davis Strait (Table 2). Proulx (1986) stated that there were 20 English vessels in Davis Strait in that year (but see Barkham 1994 for problems with the accuracy and reliability of Proulx [specifically Proulx 1993, but the issues are relevant to this publication as well]). In 1788 I estimate 51 English vessels in Davis Strait; however Danish sources indicated that there were 90 "English" whalers in West Greenland waters (Gad 1982). Even when the seven Scottish vessels (Sanger 1985, unpublished) are added the total number of British vessels is much lower than 90. These two points suggest that Scottish whaling effort may not be

representative of English whaling effort. Detailed archival research would be required to address these issues.

Another source of whale products for British markets was barter between the Hudson's Bay Company (HBC) and Hudson Strait Inuit. The baleen from a minimum of 115 bowhead whales was collected between 1737 and 1800 (Barr 1994). This excludes baleen collected by HBC supply voyages from 1670-1736 and 1801-1913 (approximately 660 trips total, Cooke and Holland 1978). Whaling in Hudson Bay was attempted by the HBC between 1767 and 1772, but was largely unsuccessful and only six whales were taken (Ross 1974, 1979a).

The total (minimum) British whale harvest therefore includes 1,519 whales taken by the Scots from 1751-1813 (Sanger 1985, unpublished), 20,312 whales taken by the combined British fleet from 1814 to 1911 (Sanger unpublished; Ross 1979a, 1993), six whales harvested by the HBC in Hudson Bay in the 1700s (Ross 1974, 1979a), 115 whales secured by the HBC through trade (Barr 1994), and an estimated 1,298 whales taken by the English fleet between 1751 and 1800 (based on data in Jackson 1978 and the assumptions noted above, and no doubt incomplete). Combining all data results in a total minimum British removal of 23,250 whales from 1737-1911.

German whaling

Germany first started whaling on the Spitsbergen grounds and was one of the leading whaling nations by the late 1600s (de Jong 1978, 1983). Ross (1979a) and de Jong (1983) provide some data on German Davis Strait whaling from 1719 to the late 1700s, although as with the Dutch the Germans were there prior to 1719 (Gad 1970; Vaughn 1986). According to Ross (1979a) the Germans caught 327 whales on 264 voyages from 1719-1792. The harvests in de Jong (1983) are lower, with 207 vessels and 277 whales from 1719-1783. For both sources the data are limited to only one port and therefore underestimate the total German harvest. Data on German whaling in Davis Strait between 1792 and 1826, when the last German vessel sailed (Hacquebord 2005), and prior to 1719, are unavailable. The harvest series, based on Ross (1979a) and updated for gaps with de Jong (1983), includes an estimated harvest of 332 whales.

Danish-Norwegian whaling in West Greenland

The Danes also first started whaling at Spitsbergen. Sporadic trips to Davis Strait were undertaken in the 1650s but no catches were apparently made (Gad 1970). Small numbers of vessels were whaling in Davis Strait in the early 1700s (Gad 1970, 1973), but the number of whales caught, if any, is unknown. Most ships sent in the 1710s and 1720s were chiefly traders, not whalers, but they secured some whalebone from Greenland Inuit (Gad 1973). In 1721 Danish colonies were established in West Greenland and a ship was outfitted specifically for Davis Strait whaling (Jones 1970; Gad 1973). Despite a trade monopoly granted in 1723, the Danes faced stiff competition from Dutch traders and were never overly successful with either whaling or trading (Gad 1973; Jones 1970). Several West Greenland whaling stations were established in the 1770s (Gad 1973), and up to eight stations and 12 ships were operating in the late 1780s (Gad 1982). Local hired Inuit did the whale hunting, using European boats and tackle. War between Denmark-Norway and England starting in 1807 impacted Greenland trade (Gad 1982), but Danish whalers were still active into the late 19th century (Vaughn 1984).

There is no complete summary of the bowhead harvest made by the Danes in Davis Strait. Gad (1973, 1982) provides some information in his narrative of the history of Greenland. Gad (1973) summarized blubber and baleen secured in trade and whales actively killed for 1721-1776. Assuming an average oil yield of 85 barrels per whale (Aguilar 1986), the minimum total number of whales secured was 179. These data are incomplete, with no information available for 27 of the 56 years. Also, sometimes an entire whale harvested by the Greenlanders was shared amongst the locals, with the traders receiving none (Gad 1973).

Gad (1982: 206) provides a graph showing the production (in barrels) of Greenland whale oil in Copenhagen from 1777-1807 (1785-87 missing), providing a more comprehensive measure of Danish-Norwegian whaling effort than previous years. The oil refined for each year was estimated (to the nearest 25 barrels) from the graph and the number of whales calculated using 85 barrels per whale (Aguilar 1986). The estimated number of whales per year ranges from 1-51, with an average of 28 whales per year and a total estimated harvest of 796 whales from 1777- 1807. An unknown proportion of these whales were harvested on the Spitsbergen grounds. Assuming an even distribution between the two grounds results in a West Greenland harvest of 398 whales. However this assumption may again not be valid, for example, the estimated harvest in 1798 was 31 whales, but only nine were reported taken in West Greenland (Gad 1982).

Harvests previous to 1777 (summarized from Gad 1973) occurred on the West Greenland grounds only and no correction for Spitsbergen harvests is thus necessary. Combining the estimated harvest from 1721-1776 (Gad 1973) with half of the 1777-1807 (Gad 1982) harvest results in a total of 575 whales. Until 1803 Greenlanders received half the blubber of whales they helped capture; after 1803 the natives received two-thirds (Gad 1982). The estimated yearly harvest was therefore multiplied by a factor of two for the years 1721-1803 and by a factor of three for 1804-1807, for a total estimated harvest of 1,208 whales from 1721-1807.

Vaughn (1984) suggested that the average Danish catch was 20-30/year at the end of the 18th century, declining to half that in 1800-1850, with only one animal per year by 1870, when only one station was still working (also see Eschricht and Reinhardt 1866; Rink 1877). The yearly average compiled from Gad (1982) for 1777-1799 is 30 whales per year, agreeing well with the upper limit suggested by Vaughn (1984). The estimated average harvest from Gad (1982) for 1800 to 1807 is 22 whales per year, much higher than Vaughn's (1984) estimate of 10-15. Shore-station whaling ended in the late 19th century (Vaughn 1984). The estimated harvest of 1,208 whales up to 1807 (Gad 1973, 1982) was therefore updated as follows: 15 whales per year were assumed for 1808-1850, dropping to 5 whales per year for 1851-1869, and dropping again to 1 per year from 1870 to an assumed end date of 1890. For this part of the harvest series I assume Vaughn (1984) implicitly included the fact that Inuit received a share of the blubber of harvested whales, and corrections were not included. The total estimated Danish harvest is therefore 1,969 whales from 1721-1890.

The Danish colonial records mentioned by Eschricht and Reinhardt (1866: 4) are available on microfilm in Copenhagen (M. Klinowska, pers. comm. in Reeves et al. 1983). Analyses of these records were started in the early 1980s (see Appendix 2 in Reeves et al. 1983, citing Klinowska 1982 unpublished manuscript, available from the IWC). Information on bowhead catches are recorded in the logbooks of the shore-stations of the Royal Greenland Trading Company, and the majority survive in the State Archive in

Copenhagen, running from 1774 to 1916 (Klinowska 1982). This document provides a brief description of the available data but did note that analyses were "not sufficiently far advanced for new data to be available" (Klinowska 1982: 2). Eschricht and Reinhardt (1866) had access to the same logbook data but unfortunately they also only mention it briefly. Klinowska (1982) examined bowhead movements (arrival and departure dates and length of stay at the different stations) and used a series of explanatory variables including catch per decade. However, instead of summarizing the Danish shore-station catches, Klinowska (1982) used the international catches summarized by Ross (1979a). It is unfortunate that neither Eschricht and Reinhardt (1866) nor Klinowska (1982) summarized the logbook data, and these would be a vast improvement over the summaries and assumptions in Gad (1973, 1982) and Vaughn (1984) that were used here to estimate Danish shore-station catches.

One additional manuscript, again unpublished, contains reference to this archived data. Klinowska and Gerslund (1983) is a proposal for continued research that was submitted to the IWC (available as SC/35/RP11). The Klinowska and Gerslund (1983) proposal summarized the logbooks ("Daybooks) for November-June from four of the nine northern shore-stations for the year 1800-1801, which reportedly represented the first year of a reasonable run of records for the area. The proposal for continued research was unfortunately not supported (M. Klinowska, pers. comm., 18 February 2008). Analyses of these archived logbooks should be undertaken, but would require time, resources, and expertise not currently available. However the microfilms are available from the IWC, and there is current interest in analyzing these data through the History of Marine Animal Populations (HMAP) project led by Tim Smith (A. Cooke, IWC, pers. comm., 19 February 2008). Analyses of these logbook data should be considered a priority for research. The four logbooks examined by Klinowska and Gerslund (1983) included a total harvest of at least 50 bowhead whales in 1800-1801, including one taken by an English vessel and 17 taken at the Holsteinborg station. The remainder were taken at four stations in Disko Bay. This represents landed whales only and is only a subset of the available logbooks. It is readily apparent that significant numbers of whales were taken by Danish shore-stations. In this harvest series I estimated Danish harvests of 42 whales in 1800 and 26 in 1801, and this is thus known to be an underestimate. However without having the Daybook data summarized for other years it is currently not possible to determine to what extent the Danish harvests may have been underestimated. While limited to one year only, the available data suggest that Vaughn (1984) may have greatly underestimated Danish whaling effort in the early 1800s.

French whaling

French vessels reportedly started whaling in Davis Strait in 1719 (du Pasquier 1986). du Pasquier (1986) provides the number of French Arctic vessels known per year from 1613-1766, although the list is incomplete and doesn't distinguish between grounds east and west of Greenland. The French fishery started to decline after the mid-1730s and ended in 1766. The government tried to revive whaling again in 1817, and du Pasquier (1986) gives the number of vessels from 1817-1837, split into the "Northern" and "Southern" fisheries only, again with no distinction between Davis Strait and Spitsbergen. The proportion of vessels in Davis Strait from 1719 -1766 was estimated based on the proportion of the Dutch fleet on the same grounds (de Jong 1978). For the years 1817-1837 the Dutch proportions are not applicable as the Dutch had essentially given up Davis Strait whaling at this time. The proportion of British harvests west of Greenland was used instead (Ross 1993). An estimated 239 French vessels whaled in Davis Strait from 1719-1766 and 1817-

1837. Using catch per vessel data for Dutch (1719-1766, de Jong 1978) and English (1817-1837, Ross 1979a) vessels, the total estimated West Greenland harvest was 608 whales. du Pasquier (1984) summarized the logbooks of 16 French expeditions to Spitsbergen from 1675-1688. The average catch per vessel was nearly always higher than the Dutch catch per vessel, and the harvest use here may therefore be underestimated. Spanish vessels were also fishing in Davis Strait by the 1730s (Ciriquiain-Gaiztarro 1961; Gad 1973), however no data are available.

American whaling

Yankee whaling started in New England in the mid 1600s as a coastal, shore-based fishery similar to that of the Basques (Stackpole 1953). In 1712 the first sperm whale (*Physeter macrocephalus*) was taken by an American vessel, launching an expansion into pelagic regions (Starbuck 1878). The first American vessel to visit Davis Strait was in 1732, and by 1737 the Davis Strait fleet from Massachusetts alone consisted of 50-60 vessels (Clark 1887; Stackpole 1953). The main targets in this fishery were sperm and right whales, but bowhead whales were likely taken as well (Jackson 1978; Reeves et al. 1983). There are unfortunately no harvest records available for this aspect of the American fishery (Jenkins 1971, Ross 1979a). The ceding of Canada to England opened up the Gulf of St. Lawrence and Strait of Belle Isle to Yankee whalers, and by the mid-1760s up to 100 New England vessels were active there (Scoresby 1820; Starbuck 1878). There are again no data available but it is likely that at least some bowhead were taken.

In the 1840s American whalers again started visiting Davis Strait and Baffin Bay (Clark 1887). In the 1850s whalers from both New England and Scotland established a shore-based fishery in Cumberland Sound (Hacquebord 2005; Ross 1979a, 1984). After 1860 American (and some Scottish) whalers moved into Hudson Bay, a predominantly American fishery that lasted until the early 1900s (Ross 1979a, 1993). Ross (1979a) contains American whaling data starting in 1846, when the Americans returned to Davis Strait and Baffin Bay, and starting in 1860 for Hudson Bay. During this time, 349 vessels caught 945 whales. American Arctic whaling occurred primarily in the Pacific region, starting in the mid 1800s (Bockstoce and Botkin 1983; Bockstoce 1986), and only a minor proportion (< 5%) of American bowhead harvests in the mid- to late 1800s occurred in the eastern Arctic (Clark 1887). Best (1987) estimated the landed catch of baleen whales made by American whalers from 1805-1909. American vessels took 248-291 bowhead whales from 1815 to 1819. This occurred before the American expansion into the western Arctic, and these whales would thus have been captured in the Strait of Belle Isle, Davis Strait and the Labrador Sea. The total estimated American harvest is therefore 1,195 whales: 945 from 1846-1915 (Ross 1979a) and 250 (50/year) from 1815-1819 (Best 1987). The harvest series has no data on whales taken in the 1700s and is an underestimate.

Canadian whaling

Some Canadian colonists reportedly tried to take up whaling in the Strait of Belle Isle and Gulf of St. Lawrence after the Basques left but were largely unsuccessful (Proulx 1986). During the American Revolution some American whalers moved north and helped build whaling industries in Newfoundland and Nova Scotia (Jackson 1978). Colonial whaling in the Gulf of St. Lawrence concentrated mostly on humpback whales (*Megaptera novaeangliae*) (Clark 1887). However in 1842 Bonnycastle wrote that whales of all species were taken in Newfoundland waters, including "the largest mysticetus or great common oil

whale of the northern oceans, which occasionally visits these waters" (Clark 1887: 217). The Little Ice Age ended ca. 1850 (Lamb 1995), so it seems reasonable that at least some bowhead whales were taken by colonial whalers prior to the mid 1800s. Unfortunately no records exist for this fishery. Shore station-based "modern" whaling began in Newfoundland in the early 1900s, but no bowhead whales were reported taken (Dickinson and Sanger 2006).

Summary of Euroamerican harvests

For all nations combined, the estimated Euroamerican (i.e., commercial) harvest is 57,507-68,736 whales from 1530-1915 AD (63,128 whales assuming a peak Basque effort of 25 vessels per year) (Figure 2, Table 3). In the eastern Arctic the most active whaling nations were the Basque and the British. There are a number of gaps in this harvest series and the total harvest may be underestimated. A number of assumptions regarding the distribution of whaling effort and average catch per vessel have been employed, and these may not be valid in all cases. Modeling approaches will need to explicitly incorporate this differing reliability of harvest estimates (see below). Despite these uncertainties the commercial harvest series is more complete than previous summaries (e.g., de Jong 1978; Ross 1979a, 1993).

INUIT SUBSISTENCE WHALING SINCE 1000 AD

The Thule culture

The Thule culture (Mathiassen 1927), direct ancestors of today's Inuit, spread eastward into the Canadian Arctic from Alaska ca. 1000 AD, eventually reaching the eastern Arctic, Labrador and West Greenland (Savelle and McCartney 1990). Bowhead whales were important to the initial Thule expansion (McCartney 1977; McGhee 1969-1970, 1972, 1975). A warming trend led to a decrease in summer ice cover, and a range expansion for both whales and whalers. The decline in whaling and abandonment of the High Arctic ca. 1500 AD was a consequence of a cooling trend that increased ice cover and decreased bowhead distribution.

McCartney (1977) distinguished between "classic" and "modified" Thule, where classic Thule (ca. 1000-1300 AD, but with significant regional variation) refers to the early culture carried from the Beaufort Sea through the Canadian Arctic and into West Greenland. The classic Thule culture coincided with the major warming episode when bowhead whales achieved their maximum range (McCartney and Savelle 1985). The modified Thule culture (McCartney 1977) refers to adaptations that corresponded to the onset of cooler temperatures, when the reduction in bowhead whale availability led to a shifting of Thule subsistence patterns. The human population largely abandoned the central and high Arctic between ca. 1400-1600 AD due to reduced whale availability. The transition from classic to modified Thule was not uniform. Schledermann (1979) noted temporal and geographic variability in Thule whaling and suggested that the "baleen period" lasted to between 1400 and 1700 AD, with the later date corresponding to sites on more open waters where whales were still accessible.

Bowhead whale bones were used extensively in the construction of Thule winter houses. Houses were built using bones with a high "architectural utility", such as mandibles, maxillae and premaxillae, ribs and scapulae (Savelle 1997). Thule winter house construction was highly variable, resulting from differing spatiotemporal availability of

bowhead whales, in addition to differences in whaling-related social status between households (Dawson 2001; Whitridge 2002).

The relative numbers of whales that were killed, as opposed to scavenged, is unknown. This has led to a questioning of the role of active bowhead whaling (Freeman 1979; Yorga 1979). However there is considerable direct and indirect evidence that bowheads were actively harvested (McCartney 1980, McCartney and Savelle 1985, Savelle and McCartney 1988, 1990). The most convincing information comes from estimates of the size of whales, as nearly all (97%) of the remains at classic Thule sites in the central Arctic were from yearling whales (McCartney and Savelle 1985, 1993; Savelle and McCartney 1991, 1994). Thule whalers actively selected for immature whales between 7-10 m in length (Savelle and McCartney 1991, 1994; McCartney and Savelle 1993), presumably related to their ease of capture.

There was significant geographic and temporal variation in Thule subsistence patterns and not all groups used bowhead whales to the same degree (Mathiassen 1927; McCartney and Savelle 1985; Savelle and McCartney 1990, 1994, 1999). Quantifying the importance of bowhead whales to the classic Thule diet has proven difficult. Bones of small animals (ringed seals, etc.) are generally considered to be "diet-derived", but bowhead bones can be "shelter-derived" as well (McCartney 1980). Bowhead whales have thus often been excluded from many zooarchaeological studies of Thule subsistence patterns (e.g., Staab 1979). McCartney and Savelle (1985), using data from Rick (1980) on faunal remains from Thule winter houses on Somerset Island, provide some rough estimates of the relative importance of bowhead whales during the classic Thule phase (i.e., pre-1300 AD). McCartney and Savelle (1985) used some very conservative estimates to suggest that at a minimum the food value of bowheads was equal to the food from all other animals combined and that the bowhead to "other" food ratio could be as high as 3:1-5:1. Savelle and McCartney (1990) conservatively estimated that one juvenile whale was equal to ca. 120 caribou or 180 ringed seals. Bowhead whales would have also been used for fuel (i.e., oil), and this may have been just as important as the food value, if not more so.

Harvest series for the Thule culture pre-1500 AD

Stoker and Krupnik (1993) summarized data in McCartney (1979), who examined whale bone winter houses at Thule sites throughout the central Arctic region (excluding Labrador and the Ungava Peninsula) and estimated that 6,301-8,215 individual whales were used. It seams reasonable to assume that nearly all whales were actively harvested (McCartney and Savelle 1985, 1993; Savelle and McCartney 1991, 1994), although the preponderance of young whale remains may also be related to different mortality rates (i.e., young whales more likely to strand on beaches). McCartney's (1979) data, as shown by Stoker and Krupnik (1993), are included in Table 4. The average number of whales used per year (i.e., harvested) was determined using the median total whale estimate and a 300 year time period (Stoker and Krupnik 1993). Each site was assigned to one of the three current Government of Nunavut regions and all estimates were rounded up to whole animals.

The Kitikmeot Region is poorly represented in Table 4, with only one location (Boothia Peninsula). However this region historically did not contain large numbers of whales and Thule Inuit there depended mostly on ringed seals and caribou (Mathiassen 1927; McCartney and Savelle 1985; Savelle and McCartney 1990). The Kivalliq Region also has poor coverage, with the only surveys in western Hudson Bay. However this area would represent the most productive whaling zone in the region (Ross 1974). Also excluded are

Ungava Bay, Labrador and Greenland (see below). Most data are for the Qikiqtaaluk Region, but this is reasonable as most early Thule whaling would have occurred in the central Arctic islands.

The classic Thule period for the different regions was defined based on Schledermann (1979) (Table 5). For Repulse Bay the baleen period occurred from 1000-1100 to 1400 AD. An average harvest of one whale per year in western Hudson Bay-Repulse Bay-Southampton Island (Table 4) over this period would result in 401 whales (Table 6). The baleen period in Cumberland Sound was from 1250 to 1650 AD (Table 5). A harvest of four whales per year (Table 4) until 1500 AD results in a total harvest of 1,004 whales. For the remaining regions in Table 4 the total harvest was 21 whales per year. I assume that the abandonment of the central and high Arctic Islands, or at least a shifting of subsistence strategies, was complete by 1500 AD. This, combined with establishment by 1000 AD, would result in a further Thule harvest of 10,521 whales. For Labrador, no harvests are added before 1500, following Schledermann (1979). For West Greenland, Schledermann (1979) (Table 5) dated the start of the baleen period as 1200 AD. A West Greenland harvest of ten whales per year (Vaughn 1984) results in an estimated harvest of 3,010 whales pre-1500. The total estimated harvest is thus 14,936 whales pre-1500 AD, peaking from 1250-1400 with an average of 36 per year (Table 6).

Quality of harvest estimates

There are several lines of evidence to suggest that the harvest series may be an underestimate. The harvest per region is based on McCartney's (1979) whalebone winter house data (as summarized by Stoker and Krupnik 1993). For at least some regions the minimum numbers of individuals (MNI) calculations in McCartney (1979) are negatively biased because large numbers of buried bones were not included (McCartney and Savelle 1985). This, combined with significant bone removal by prehistoric and historic Inuit, in addition to contemporary Inuit for whalebone carvings (McCartney 1979), significantly reduced the amount of bone counted at some sites. In addition, not all whale crania or mandibles ended up in winter houses, with many left on beach processing sites or stockpiled in caches for future architectural use (Savelle 1997). The estimated yearly harvest for Somerset Island is only eight whales (Table 4), yet the caches there could have stored the meat and blubber of 15-25 animals (Savelle and McCartney 1990). In comparison to most commercial data, the Inuit harvest estimates are the least reliable (see below).

Harvest series for the Thule culture post 1500 AD (pre-"historic")

Thule whaling declined in the central Arctic after 1500 AD, before the start of widespread commercial whaling. Bowhead whaling survived only on the western coast of Baffin Island, Hudson Bay, West Greenland and Labrador (Stoker and Krupnik 1993). Schledermann (1979) suggested that deteriorating climate conditions in the central Arctic resulting in population movement into regions where open water conditions allowed continued hunting of bowhead whales. For the post-1500 AD Thule harvest I assumed that bowhead hunting continued only in the locations noted above and again used the baleen period dates in Table 5. For western Baffin Island, the five locations in Table 4 (Navy Board and Pond inlets, Clyde area, Broughton area, Cumberland Sound and Frobisher Bay-Hudson Strait-Foxe Peninsula) have a combined total of 11 whales per year. Assuming the baleen period ended at 1650 AD (Table 5) for all these regions results in a total harvest of 1,650 whales from 1501-1650 AD.

For Labrador the "baleen period" ended in 1700 AD (Table 5). Assuming a harvest of five whales per year (average harvest at the time of initial Moravian contact, Taylor 1988 – see below) results in 1,000 whales 1501-1700 AD. According to Schledermann (1979) the Thule site at Repulse Bay (Naujan) was occupied until 1400 AD (Table 5). However after ca. 1500-1600 AD whaling again occurred in western Hudson Bay (Stoker and Krupnik 1993). Assuming a harvest of five whales per year (see below) results in a total western Hudson Bay harvest of 1,000 whales 1501-1700 AD. For West Greenland a harvest of ten whales per year (Vaughn 1984), or five each in the northwest and southwest, is again assumed. The baleen period lasted until 1550 AD in northwest Greenland and 1650 AD in southwest Greenland (Table 5), for an estimate of 1,000 whales from 1501-1650 AD. The combined estimated harvest for 1501-1650/1700 AD is 4,650 whales, peaking early (1501-1550) with an average of 31 whales per year (Table 6).

Historic Inuit bowhead whaling

The Historic Inuit period also exhibits significant geographic variation, with definitions largely dependent on the time of first European contact. For example, McCartney (1977) defined the historic period in Hudson Bay as starting in 1610. In West Greenland, the first extensive European contact did not begin until Danish-Norwegian colonization in 1721 (Gad 1973, Rink 1877), although there was limited contact with European traders and whalers before this time. A similar situation occurred in Labrador where there was only limited contact until the late 18th century when Moravian mission stations were established. Inuit on Baffin Island were in contact with European explorers starting in the 1600s (in addition to possible contact with the Norse before this, Fitzhugh 1985). European (and American) contact in the Canadian eastern Arctic culminated in the mid-1800s with the presence of many commercial whalers, which had a profound effect on local Inuit (Ross 1974, 1979b). In this case, all dates begin, somewhat arbitrarily, to bridge the gap between Schledermann's (1979) "baleen period" dates (Table 5) and those discussed in this section.

A large body of literature exists from whalers, explorers and missionaries, and some early ethnographic accounts of native whaling are available (Boas 1888; Cranz 1820; Egede 1745; Oswalt 1979; Parry 1824, 1826; J. Ross 1819). These accounts, while clearly indicating that early historic period native whaling occurred, are brief and of little value in reconstructing harvest numbers. In most cases the authors were less concerned with describing Inuit harvesting practices than they were with general ethno-cultural observations or notations of discoveries.

Many of these ethnographic accounts also described situations in which early European whalers had already reduced whale populations and had a significant effect on Inuit culture, thus impacting the very lifestyles they described (Taylor 1979). The presence of Euroamerican whalers in places such as Pond Inlet, Cumberland Sound and northwest Hudson Bay may have had a significant effect on the native harvest of bowheads. Both Clark (1979) and Freeman (1979) suggest that trade with Euroamericans may have created renewed interest in bowhead whaling among Inuit. In many cases, a number of Inuit harvested whales are likely included in the totals for other countries through trade of baleen and blubber. Despite these shortcomings, historic ethnographic accounts are of some value in reconstructing Inuit bowhead harvests during the early contact period, although a number of assumptions are necessary.

Historic whaling in Nunavut and Nunavik waters

Some limited data are available for three areas in Nunavut: Cumberland Sound, southeastern Baffin Island on Hudson Strait, and northwest Hudson Bay.

Cumberland Sound

Some data on contact-period Inuit whaling are available for Cumberland Sound, which commercial whalers first entered in 1839 (Haller 1966, in Taylor 1979). In 1840 Penny observed freshly killed whales in Cumberland Sound (M'Donald 1841), and stated that Inuit there killed "annually from 8 to 12 whales", something worth noting as it was "peculiar to these Esquimaux" (Penny 1840, in Stevenson 1997: 40). Captain Penny travelled extensively in the region and was very familiar with western Baffin Island, and his statement suggests that by the mid 1800s bowhead whaling in this area was largely limited to Cumberland Sound. This agrees well with a statement from a contemporary Inuit elder from Pond Inlet, who noted that local Inuit reportedly harvested few bowheads in the historic period leading up the arrival of Scottish whalers, who then hired local Inuit hunters (J. Alooloo, Pond Inlet elder, pers. comm., 18 April 2007).

However Penny's statement is contradictory to both Schledermann's (1979) "baleen period" end of 1650 AD (Table 5) and the estimated annual harvests from archaeological evidence (Table 4). Two possibilities may explain the discrepancy in dates. First, the presence of foreign whalers and traders, and thus foreign trade items, prompted the Inuit to increase bowhead harvests strictly as a trade item (Clark 1979; Freeman 1979). The second possibility, and the one preferred by Stevenson (1997), is that Schledermann's (1979) stratigraphic sequence was correct but that his chronological and cultural interpretations were not. Regardless of the reason, the available ethnographic evidence suggests that in the early to mid-1800s Cumberland Sound Inuit took an average of ten whales per year, a high harvest level unique to this region. For the discrepancy in annual harvest numbers, it is worth noting the earlier discussion regarding the likely underestimates of pre-contact harvest due to the limitation of using whalebone houses only. Another possibility is increased population size in Cumberland Sound due to migration from central and high Arctic regions with cooling climatic conditions (Schledermann 1979).

Hudson Strait

Barr (1994) presented data on baleen secured by Hudson's Bay Company ships in Hudson Strait and Hudson Bay (here included with British whaling harvests). Most baleen came from Hudson Strait (78% of the total from 1737-1778), and then mainly from the Kimmirut area. Barr (1994) estimated that between 1737 and 1800 the products of 65 average bowhead whales (i.e., one per year) were traded by Inuit of southern Baffin Island. In some years the equivalent of three to five average whales was traded (Barr 1994). In Labrador, only 24 of 63 whales (38%) killed from 1771-1784 were reported as having marketable baleen over 1.8 m long (Taylor 1988). Given this information, along with the cultural (i.e., Thule) tradition of selection for small whales, it seems likely that during the mid through late 1700s an average of three whales per year were being harvested by Inuit along the northern side of Hudson Strait, with harvests in some exceptional years possibly exceeding ten whales.

Ross (1974) presents evidence that the Inuit harvest decreased by the late 1800s. In 1880 Inuit took three whales under contract to an American whaling firm, and a whaling/trading station was established in central Hudson Strait shortly after. By this time commercial whaling had already reduced whale numbers in Hudson Bay. Inuit occasionally took whales using boats supplied by the station but numbers were not large. In 1886 local Inuit stated that no whales had been taken in three years (Ross 1974). Maxwell (1979) summarized archaeological and ethnographic information for the Kimmirut region and suggested that small numbers of bowhead whales may have been harvested up until 70 years ago (i.e., the early 1900s). Much of the baleen was probably traded and is thus likely included in the harvest series for American and Scottish whalers (Ross 1974, 1979a; Sanger unpublished).

Western Hudson Bay

The Hudson's Bay Company also secured baleen along the western Hudson Bay coast, although amounts were much lower than in Hudson Strait (Barr 1994). From 1737-1788 Barr's (1994: 242) Table 2 includes only 7,058 lbs of baleen traded at Churchill and another 7,032 lbs secured by expeditions north to Marble Island. This equals a total of ca. 10 average-sized bowhead whales over the 42 year period, or an average of one whale every four years. Ross (1974) also summarized Hudson's Bay Company trade between Churchill and Marble Island and gave similar numbers. Hearne (1795) witnessed three whales harvested near Churchill in a 20-year period prior to 1795, and Hudson Bay Inuit killed one whale, and struck and lost two, in 1828 (Reeves et al. 1983). Given the suggestions above for Hudson Strait harvests, an average of one whale per year may have been taken in Hudson Bay from Marble Island south.

The presence of whale bone on eastern Melville Peninsula suggests a long history of bowhead harvesting in Foxe Basin continuing into the historic period. However, Parry (1824) was informed by local Inuit that most whales were met with in the Repulse Bay area. The estimates above based on the baleen trade do not include the Repulse Bay region, which would have been the most productive area for bowhead whaling in Hudson Bay. It may be reasonable to assume that an average of one to two bowhead whales was taken in the area every year. Harvests likely declined in the later 1800s as they did in Hudson Strait (Ross 1974).

Total estimated Nunavut and Nunavik harvest, "historic" period

For the "historic" period, harvests in Nunavut and Nunavik end in 1860. This date corresponds to the initiation of commercial whaling in Hudson Bay and occurs just after the establishment of shore stations in Cumberland Sound in the mid-1850s. Some whales were likely harvested after 1860 (e.g., Maxwell 1979, Ross 1974), but most whale products would have been traded to American and Scottish whalers and thus included in the commercial harvest series for those countries. Assuming Penny's estimation of 8-12 whales per year (Stevenson 1997) is correct, this would result in a total Cumberland Sound harvest of 2,100 whales (i.e., 10 per year) from 1650-1860. However the discrepancy between the harvest levels in Table 4 and Penny's statement is still unresolved. In addition, the commercial harvests off West Greenland in the 1700s reduced the bowhead population, and may have negatively impacted Inuit harvest levels. For northern Hudson Strait (southern Baffin Island), an average of three whales per year is assumed for 1701-1860, for a total of 480 whales.

For southwestern Hudson Bay (south of Marble Island), an average harvest of one whale per year is assumed, for a total harvest of 160 whales from 1701-1860. Assuming a combined average yearly harvest of two whales in Repulse Bay and Foxe Basin results in an additional 320 whales from 1701-1860. No bowhead harvest data are available for Nunavik (eastern Hudson Bay and southern Hudson Strait). McCartney (1979) excluded the Ungava Bay region, so there is no archaeological data and any harvests in this region were thus excluded from the pre-contact harvest series. There are also no ethnographic accounts for harvests, but contemporary Inuit have suggested that Nunavimmiut may have traditionally harvested a maximum of 3-4 bowheads per year (A. Kullula and J. Peters, Makivik Corp., pers. comm., 14 March 2007). A conservative estimate of two whales per year results in another 320 whales from 1701-1860. The majority of Nunavik harvests would have occurred in northeast Hudson Bay and Hudson Strait, however Inuit have reported bowhead occurrence during winter at some of the more southern islands on the east side of Hudson Bay (Low 1906). Inuit on the Belcher Islands, in southeast Hudson Bay, reportedly have a historic tradition of bowhead whale hunting (L. Arragutainaq, Sanikiluaq Hunters and Trappers Organization, pers. comm., 7 September 2007). Harvests in this region of Hudson Bay may thus have been higher than assumed here.

The total estimated harvest in Nunavut and Nunavik for the period 1651/1701 (depending on region) to 1860 is 3,530 whales (Table 6). The harvest series is based on scattered ethnographic accounts and a number of assumptions which may or may not be valid. While these estimates are based on the best data available there is unfortunately no way to determine the level of bias. One source of negative bias is the at least occasional harvests in other regions. For example, in 1869 Inuit in Admiralty Inlet killed five large whales (Hall 1876). It is unknown whether historic Inuit in this or other excluded regions harvested whales on a regular basis.

Labrador

Bowhead whaling was introduced to Labrador by Thule migrants at least by 1500 AD (Kaplan 1985) and possibly as early as 1350 AD (Jordan 1978). The estimated harvest between 1501 and 1700 AD was 1,000 whales (five per year), based on Taylor's (1988) data that showed an average of 4-5 whales per year were harvested during the early contact period (1771-1784). Direct contact with Europeans before this time was minimal, and the early Moravian mission records used by Taylor (1988) represent a whaling complex that was aboriginal in all but a small number of technical adaptations (Taylor 1979). A number of historical sources are available starting in the late-1700s, and these provide information on bowhead harvests during the historic period. In 1771 Moravian missionaries encountered Inuit who wanted to barter baleen (Hillier 1967 in Schledermann 1979), signifying a long-standing tradition of trade with Europeans. This suggests a continuation of active bowhead whaling between 1700 and the establishment of the Moravian missions in 1771. The estimated harvest for 1701-1770 is thus 350 whales.

Labrador is unique relative to other eastern Arctic regions in that there are detailed historical accounts of native bowhead whaling. Taylor (1974, 1988) summarized known harvests in Labrador using Moravian mission documents; these data were updated with Brice-Bennett (1978) and Reeves et al. (1983). From 1771-1849 Labrador Inuit harvested a minimum of 107 bowhead whales (plus another 36 struck and lost), and found 56 drift whales (which were likely struck and lost in Davis Strait before drifting to the Labrador coast) (Table 6).

West Greenland

Extensive contact between West Greenland Inuit and Europeans started with Danish-Norwegian colonization in 1721 (Gad 1973). The Danes were never overly successful in their whaling enterprises, often facing stiff competition from English, Scottish and Dutch vessels. For the harvest series, a harvest of five whales per year for southwest Greenland is assumed for 1651-1721, for an estimated 355 whales. After colonization some whale products were traded and therefore included in Danish-Norwegian commercial harvests. However in many cases Inuit harvested whales and kept all products for their own use, so an average of three whales per year was assumed for the period 1722-1770 (before the establishment of Danish shore stations, Gad 1973). The total estimated West Greenland harvest for this 49-year period is 147 whales.

The Greenlandic hunt for bowhead whales lost its importance in the late 18th or early 19th century due to declining stocks, which prompted a shift to other large whales such as humpbacks (Caulfield 1993; Kapel 1979; Kapel and Peterson 1982; Rink 1877). In the mid to late 1800s West Greenlanders averaged one bowhead whale per season (Rink 1877), supplemented by several drift whale carcasses and one or two humpback whales. Assuming an average harvest of one bowhead per year from 1771-1900 results in an additional 130 whales taken.

Summary of historic period whaling

In summary, an estimated total of 4,655 whales were taken by Inuit in eastern Canada and West Greenland during the historic whaling period (Table 6). This is remarkably similar to the 4,650 whales estimated to have been taken after 1500 AD but before the historic (contact) period.

Inuit harvests post-commercial whaling

In many areas a tradition of native bowhead whaling that existed as recently as the late 1800s did not persist into the 20th century (Kapel 1979; Kapel and Peterson 1982; Reeves and Mitchell 1985; Caulfield 1993). Commercial overexploitation was undoubtedly a major factor in this discontinuation. However, after commercial whaling ended there were continued but sporadic Inuit harvests throughout the 20th century, often using equipment left by commercial whalers.

Mitchell and Reeves (1982) and Reeves et al. (1983) summarized known harvests and whales struck and lost after 1915. Hay et al. (2000), Gaston and Ouellet (1997) and Richard (2000, containing comments by R.R. Reeves) provide several additional records. In 1985 hunters shot a whale near Arviat; it is unknown whether they killed the animal, but a carcass washed ashore nearby soon after (Stewart et al. 1991). Only three whales were reported harvested in West Greenland during the 20th century (Kapel 1979; Kapel and Peterson 1982; Reeves and Heide-Jørgensen 1996). One young (9-10 m) bowhead whale was killed in a beluga whale net in northwest Greenland in autumn 1980 (Kapel 1985), for a total known West Greenland kill of four whales post-commercial whaling. Nunavik Inuit reportedly harvested a whale in 1979 (A. Kullula and J. Peters, Makivik Corp., 14 March 2007, pers. comm.) that was not included in the sources above. In total, a minimum of 36 whales were killed, with another 14 struck and lost and three drift whales utilized, by Canadian and Greenland Inuit from 1918-1988. Documentation is sporadic and opportunistic, and these harvests represent minimum values. Most reports summarized by

Mitchell and Reeves (1982) came from published sources (e.g., Degerbøl and Freuchen 1935; Sutton and Hamilton 1932) or HBC post journals, and all are limited in time and space. Mitchell and Reeves (1982) suspected that considerably more whaling had taken place than was reported.

In recent years Canadian Inuit have been issued licenses to conduct subsistence harvests. In 1994 there was an unlicensed kill in northern Foxe Basin, and since then there have been five licensed harvests: 1996 in Repulse Bay, 1998 in Cumberland Sound, 2000 near Coral Harbour, 2003 in northern Foxe Basin, and 2005 again in Repulse Bay. In 2004 another bowhead was caught in a net in West Greenland; a kill was attempted but the whale escaped after being injured with rifles (Siku Circumpolar News Service 2004). Prior to 2003 eight bowhead whales were reported entangled in nets in eastern Canada and West Greenland (DFO, unpublished data). Since that time an additional four whales have been reported to be entangled – two in 2005 and one in 2006 in Nunavut, and one in Disko Bay in 2003 (DFO, unpublished data). It is unknown if this 2003 report from West Greenland represents confusion with the whale that was reportedly entangled and then shot (but escaped) in 2004 (Siku Circumpolar News Service 2004). The fates of these whales are unknown, but all reportedly disappeared with at least part of the net. However given that they were not shot at (except the 2003 or 2004 whale in West Greenland), they were not included as harvested whales in the catch series. Thus, the total (minimum) harvest between 1918 and 2005, for both eastern Canada (with no known harvests in Labrador) and Greenland combined, is 56 whales, including 14 struck and lost (Table 6). Nunavummiut will hunt at least one bowhead whale in 2008, and Nunavik Inuit have also requested a bowhead licence. West Greenland Inuit will begin a limited subsistence hunt in 2009, with an International Whaling Commission quota of two strikes per year for five years.

Summary of Inuit subsistence harvests

In total, an estimated 24,247 bowhead whales may have been harvested by Inuit in eastern Canada and West Greenland since 1000 AD. Most (15,785 whales, 65%) were taken before commercial whaling became established ca. 1530 AD. There are a number of assumptions included, based on limited and sometimes contradictory data, and unfortunately testing of these assumptions will be difficult. Inuit harvest levels post-1530 AD are small in relation to commercial harvests (Figure 4), and these harvests would likely have remained sustainable had commercial overexploitation not reduced the whale population to low levels.

TECHNOLOGICAL ADVANCES IN WHALING

The entire history of Arctic bowhead whaling can be considered "traditional" whaling, in contrast to the "modern" whaling of the late 1800s and 1900s. The technological differences between the two eras are profound. Modern whaling employed numerous technological advances including floating factories, harpoon cannons, and fast steam-powered catcher boats, enabling the capture of the fastest baleen whales. Arctic bowhead whaling utilized hand harpoons from small man-rowed whaleboats, and, for almost its entire history, depended on sailing vessels to make their way through Arctic ice fields. Nonetheless, there were some technological advances throughout the history of bowhead whaling.

In the early years vessels were usually multipurpose ships (de Jong 1978). When ice fishing started off Spitsbergen in 1660 the Dutch and Germans started fortifying vessels with an extra layer of planks and extra beams and knees to resist the pressure of ice floes (de Jong 1978). The British first tried fortifying a ship against the ice in 1790, but it was a failure as the ship was crushed (Jackson 1978). The biggest technological advance in Arctic whaling vessels was the use of steam power to easier penetrate through the Arctic ice. The first steam whaler sailed from Hull in 1857 (Jackson 1978). Scotland had better luck with steamers than the English ports, and their whaling and sealing fleets quickly became dominated by steam-powered vessels. Between 1861 and 1881 the Scottish fleet changed from 13% to 95% steamers (Jackson 1978), including the entire Dundee fleet by 1873 (Clark 1887; Jackson 1978). During the second half of the 19th century a small fleet of Scottish steamers regularly voyaged through the North Water (Dunbar 1972; Vaughn 1991). By the 1870s Scottish vessels were predominately steam powered, and their catch rates were almost always higher than sailing vessels (Table 7). However they did not consistently outperform sailing vessels, and in some years sailing vessels caught more whales on average. However even when the average catch per vessel was higher for sailing vessels steam-powered vessels caught larger whales (Sanger 1991). The large technological advances given by steam vessels, chiefly the opportunity to penetrate further into the Canadian Arctic, occurred during the final days of the eastern Arctic bowhead hunt, when bowhead numbers were low. The vast majority of Arctic bowheads were taken by sailing vessels.

Most bowhead whales taken in eastern Arctic waters were caught using hand harpoons, and harpoon cannons were never successfully used in this fishery. However there were attempts, by several nations, to invent a suitable cannon. The Danes attempted to build their own several times from the 1760s to 1780s, and experimented with an English-built canon in the 1790s (Gad 1982). Some British whalers had experimented with harpoon guns in the 1730s (Sanderson 1956), again at Disko in the 1790s (Gad 1982), and yet again in 1821 (Jenkins 1971). Over time the inventions improved in quality, but whalers generally preferred to use a hand harpoon. The harpoon cannon never became popular until the "modern" whaling era. The modern harpoon gun was invented in 1860 by Sven Foyn, a Norwegian sailor, and came into popular use in the 1880s.

Another whaling invention that improved catch efficiency was the tail knife. It came into use with both Danish and British whalers in the early nineteenth century (Gad 1982; Scoresby 1820). It was created to cut the whale's tendons and muscles, preventing it from using its tail. Greenland Inuit were reported to be extremely pleased with its efficiency (Gad 1982). Alaskan Eskimo whalers have improved their efficiency rates (i.e., proportion of struck whales landed) from ca. 50% to ca. 20% in recent years, chiefly due to the introduction and use of improved explosive harpoon technologies (Hess 1998; Suydam and George 2004).

CATCH PER UNIT EFFORT (CPUE)

Environmental conditions, timing, technology, experience and luck all played large roles in whaling success and the catch per unit effort (CPUE) of individual vessels. Data on CPUE effort is likely more a reflection on these various factors than a suitable index of bowhead population size. Throughout the history of bowhead whaling certain nations were superior to others, and dominated the industry. For example, in Spitsbergen in the late 1600s the average catch per vessel was nearly always higher for French vessels than for Dutch vessels (du Pasquier 1984). There were thus consistent nation-level differences in CPUE.

The Dutch industry at Spitsbergen dominated the British because of differences in socioeconomic factors such as low interest rates, cheap skilled labour, and efficient shipbuilders (de Jong 1978; Elking 1722; Jackson 1981; Scoresby 1820 Vol. 2). Similar impacts of socioeconomic factors can be seen in British-American competition in the early 1800s (Davies et al. 1987). The Dutch had displaced the British in the 1600s and 1700s, but then in turn they were replaced by the British in the late 1700s (Davis et al. 1987; Ross 1993). Diversification also helped fleets remain competitive. In the late 1800s the Scottish fleet used the profits from sealing near Newfoundland to subsidize bowhead whaling, allowing them to remain profitable despite a much-reduced bowhead population (Sanger 1980).

Figure 6 shows catch per unit effort from 1719-1915 for five nations for which such data are available (from de Jong 1978, 1983; Ross 1974, 1979a; Sanger 1985, unpublished). During the early years of the Davis Strait fishery, CPUE was similar for Dutch and German vessels, but in the late 1700s and early 1800s the Scottish fleet had catch per vessel rates that were much higher that those obtained by the previous fleets (Figure 6a). Much of this early Scottish effort occurred along the West Greenland coast, on grounds that were already showing signs of depletion by this time (Reeves et al. 1983). This suggests that the Scots were better whalers and that CPUE may not always be an effective index of bowhead abundance. Scottish CPUE increased dramatically after the 1817 expansion into western Baffin Bay, and the English vessels enjoyed a similar level of proficiency until they stopped whaling in the 1860s. In the late 1800s the Scottish fleet clearly dominated over the Americans, and this was likely the result of improved technology (i.e., steam vessels) and more experience with Arctic whaling. Catch per unit effort generally increased with increasing harvest levels (Figure 6b), and six of the top ten years for harvests are also among the top ten years for CPUE. The two highest CPUE values occurred in 1832 and 1833, which were also the two years with the highest harvests (1832: CPUE = 24.01 whales, harvest = 1,483 whales; 1833: CPUE = 22.26 whales, harvest = 1,668 whales). However Klinowska (1982) found no significant correlation between total catch and the number of ships.

Climate had a significant influence on the movements of both whales and whalers (Vibe 1967; Klinowska 1982). Environmental factors such as poor weather and hazardous or difficult ice conditions played a huge role in success for both commercial (e.g., Lubbock 1937; Klinowska 1982; Ross 1993; Bockstoce et al. 2005) and Inuit subsistence whalers (Taylor 1974; George et al. 2003; Suydam and George 2004). Along the West Greenland coast fewer whales were caught in summers with more ice (Klinowska 1982). Both whales and ships were often lost due to poor weather and ice conditions (Mitchell and Reeves 1981; Reeves et al. 1983). In "close-seasons" the land-floe ice edge extended across Lancaster Sound and blocked the whale's westward migration; and whale harvests were typically high in these years (Finley and Darling 1990; Lubbock 1937; Reeves et al. 1983). A close season occurred in 1823, and this year is characterized by the third-highest whale harvest and fourth highest CPUE. Other years in the 1820s and 1830s with high harvests and CPUE levels (e.g., 1832, 1833) may have been similar close-seasons, with high CPUE values being related to environmental conditions. However in some cases changes in harvests and CPUE may have been directly related to changes in whale abundance, as CPUE did increase with the evolution of new grounds, for example during the 1830s after the whaling fleet managed to access the large numbers of bowhead whales in the vicinity of northwest Baffin Island (the "west water"), and again after 1860 with the start of whaling in Hudson Bay (Figure 6b).

STRUCK AND LOST RATES

All of the harvest estimates presented here are the number of landed whales only, with no accounting for whales which were struck and lost (except for the recent Inuit harvests). Struck and lost animals include those which were harpooned and escaped, to presumably die, those that were killed but lost due to bad weather, breaking lines, etc, and those products that were on ships which sunk or burned. For population modelling it will be necessary to estimate the percentage of whales that were killed but not retrieved. Woodby and Botkin (1993) reported a 24% loss rate for the Bering Sea stock during the nineteenth century. Mitchell (1977) used a 15% S/L rate for Hudson Bay and a 20% S/L rate for Davis Strait in his calculations of pre-exploitation bowhead population sizes. Mitchell and Reeves (1981) and Woodby and Botkin (1993) used similar values (also see IWC 1992). In modeling the Spitsbergen bowhead stock, Allen and Keay (2006) used a loss rate of 20%. Those authors tested the sensitivity of their model, and an increase in loss rate to 25% or a decrease to 15% resulted in only slight changes (ca. 4%) to the pristine stock estimate. However, Small (1971) estimated struck and lost rates of 20% for the early years of modern Antarctic whaling (1909-1925). Loss rates in early Arctic bowhead whaling, with its technological limitations, were likely much higher.

In the 1780s the Danish Greenland colonists made a concerted effort to get the Greenlanders to stop whaling from umiaks due to high struck and loss rates (Gad 1982). By 1788 Greenland Inuit employed in Danish whaling were all using the new "European" methods with Danish sloops, ropes, and tackle. Even with improved equipment, colony whalers lost a large number of whales. Between December 1779 and mid-May 1780 whalers at Godhavn caught two whales but lost five (Gad 1972). Klinowska and Gerslund (1983) summarized struck and lost rates at three Danish shore stations for 1800-1801, and loss rates ranged from 21% to 75% (eight landed and 6 lost at the Vester Eiland station). For the three stations combined, a total of 28 whales were landed, and 13 were struck and lost (overall loss rate 46%). Of these 13 whales, two were definitely dead; and a third was lost with five harpoons and four lines attached and assumed moribund (Klinowska and Gerslund 1983). Two additional whales were reported lost at Ritenbank (a secondary report from the Godhavn logbook). In recent years (since the mid-1990s) ca. 80% of the bowheads struck by Alaskan subsistence whalers are landed (Suydam et al. 2007), although in the past up to half those struck were lost (Hess 1998). Technological improvements have resulted in this increase in the proportion of whales landed, but the majority of struck but lost whales are considered to have a poor chance of survival (Suydam et al. 2006, 2007).

French whalers after Southern right whales (*Eubalaena australis*), a closely related species with similar characteristics and behaviours, in the 1700s and 1800s lost 30-40% of the whales struck (du Pasquier 1986). The International Whaling Commission (IWC) has used correction factors of 1.2-1.6 for assessments of global right whale populations (IWC 1986, 2001). These correction factors may be too low, given that Scarff (2001) estimated a struck-lost correction factor of 2.4X for pre-modern pelagic whaling for Pacific right whales (*Eubalaena japonica*). Hacquebord (2005) suggested that the Basques caught approximately 300 whales per year in Grand Bay, but struck and lost another 150 (i.e., a S/L factor of 1.5). Bad weather was also a factor in the loss of killed whales. In 1852 a British whaler caught four whales along the northwest Baffin Island coast, but severe weather caused three to break adrift from the boat and be lost (Reeves et al. 1983). In some years large numbers of ships were lost, often with cargoes on board. At least 82 ships were lost in Davis Strait from 1819-1843 (Mitchell and Reeves 1981). During

population modeling the sensitivity of varying struck and lost rates will need to be examined, but it is likely that they were higher than the 15-20% used previously (Mitchell 1977; Mitchell and Reeves 1981; Woodby and Botkin 1993), at least for some nations and eras.

AGE AND SEX SEGREGATION OF HARVESTS

Bowhead whales exhibit considerable age- and sex-based segregation in their spatiotemporal distribution (Finley 1990; Dueck et al. 2006; Heide-Jørgensen et al. 2006). In Disko Bay, West Greenland, few calves or juvenile whales have been observed in recent decades, and this pattern is consistent with observations made during the commercial whaling period (Eschricht and Reinhardt 1866; Heide-Jørgensen et al. 2007). Most (85%) bowhead whales in Disko Bay in spring are large adult females > 14 m long that are unaccompanied by calves (Heide-Jørgensen et al. 2007; Laidre et al. 2007). Foxe Basin is an important nursery area for females with calves and is characterised by a large population of juvenile whales and cows with calves (Cosens and Blouw 2003). Commercial whalers did not enter Foxe Basin so it is unknown whether this population structure was the same historically.

Klinowska and Gerslund (1983) suggested that the Disko Bay region was a calving ground, based on the catch of a pregnant female in April 1801 (also noted by Eschricht and Reinhart (1866) in addition to the catch of a very small calf in May of the same year. This animal was reportedly ca. 3.8 meters long (12 Danish feet, or "fod"), with baleen 0.9 m long (3 fod). The foetus from the pregnant female was reported to be 4.7 m long (Eschricht and Reinhart 1866; Klinowska and Gerslund 1983), considerably larger than the young calf. The length of the baleen plates were also significantly longer than that reported for bowhead calves from Alaska (60 cm, George and Suydam 2006). However the Danish logbooks gave measurements to the nearest 10 fod (3.14 m) (Klinowska and Gerslund 1983) and the length of the calf may have been overestimated. Given the known gestation lengths of bowhead whales (Koski et al. 1993), and the fact that most bowhead whales currently observed in West Greenland are large adult females (Heide-Jørgensen et al. 2007; Laidre et al. 2007), it is not surprising that pregnant females were found there in spring. Alaskan bowhead calves are usually born between early April and early June (Koski et al. 1993), but births have also been observed in Foxe Basin as late as June (Hay et al. 2000). Most calves however are born before the females arrive in Foxe Basin.

There are limited data available on the sex and age composition of commercial bowhead harvests in Hudson Bay. Reeves and Cosens (2003) summarized logbooks of American whalers from 1862-1905 and provided the age and sex of 164 whales that were struck, killed or sighted. All age classes were represented, with calves making up ca. 16%, subadults 32% and adults 52% of the harvests. Sex was not reported for the majority of adult whales (64 of 85), but most with data were females (17 of 21 adult whales). Northwestern Hudson Bay may have also been a historically important nursery area. Spring whales taken at the floe edge in Cumberland Sound were generally small, but those taken in the fall were usually large (Reeves et al. 1983).

Some data are also available for British whaling catches in Baffin Bay. On the "south-west fishing" ground whales of both sexes were taken and they were usually large (Duncan 1827; Lubbock 1937; Reeves et al. 1983). Finley and Darling (1990) summarized the logbook from the whaling vessel *Cumbrian* in 1823 (also in Lubbock 1937; Reeves et al. 1983). This vessel took adult whales of both sexes (at a near 50:50 ratio) in addition to

calves. For non-calves (known by whalers as "suckers"), males ranged in size from 9.1 to 16.2 m, and females were generally larger (12.8-17.1 m). Reeves et al. (1983) summarized data from the *Abram* in 1839, which took large whales of up to 18 m long (Finley and Darling 1990) on the rock-nosing grounds along the east coast of Baffin Island. This "rock-nosing" was a specialized bowhead fishery that occurred along the east Baffin coast in the fall and was directed at large whales. In 1827 the *Cumbrian* took 18 whales which were all adults (> 13.7 m), and these whales may have been taken along the east coast of Baffin Island (Finley and Darling 1990). Some years were considered "close-seasons", in which heavy ice conditions excluded whalers from Lancaster Sound. In these years whalers typically encountered large numbers of small whales along the Lancaster Sound ice edge, and total yields were lower due to the prevalence of small whales (Lubbock 1937; Reeves et al. 1983; Finley and Darling 1990).

Klinowska and Gerslund (1983) provide total length data for nine whales harvested in Disko Bay (the "east side" grounds) in 1800-1801, including the calf noted above. The other eight whales were all large adults ranging in size from 15.7 to over 25 m. This 25 m animal is considerably larger than contemporary adult whales and likely represents an overestimation do to rounding up. Two additional whales had baleen lengths over 2.51 m (8 fod), and two had baleen lengths over 3.14 m (10 fod); thus also representing adult whales. The calf noted above was captured at the same time as an adult whale over 18 m long (but again note the potential for significant rounding errors). These limited data suggest that the historical bowhead population in West Greenland was similar to that observed there today (i.e., mostly large adult females) (Heide-Jørgensen et al. 2007; Laidre et al. 2007).

The average yields recorded during the later stages (after 1860) of the Baffin Bay fishery, after the introduction of steam power, suggest that the industry was consuming smaller whales, a similar pattern as that observed on the Spitsbergen grounds (Finley 1990; Finley and Darling 1990). During the 1870s steam-powered vessels were able to penetrate the "nursery grounds" in Prince Regent Inlet (Ross 1985). Markham (1874) presented baleen length data on whales taken by the *Arctic* in 1873, mostly from Prince Regent Inlet (also in Finley and Darling 1990; Sanger 1991). The harvest was again comprised of calves and large whales, with a sex ratio of non-calves again approaching 50:50. Total whale length was estimated using the regression equation of Lowry (1993) (also see Reeves and Cosens 2003). Females taken ranged from ca. 6 m to over 16 m in length, and males were again slightly smaller, up to ca. 15.8 m. Sanger (1991: Table 2) summarized the baleen lengths of 31 whales harvested by 16 Scottish steam voyages to Davis Strait between 1885 and 1890. Most (29 of 31) whales were adults, and total length ranged from 11.1-19.2 m (mean 15.8 m). Most whales currently observed during autumn in Isabella Bay (Baffin Bay) are large adults > 13 m long (Finley 1990), suggesting that current segregation patterns are similar to those historically.

Cuumba (1986) examined bones from the Basque whaling station at Red Bay, and nearly all were from adult whales. Only one young animal (8-9 m total length) was found in 17 individual whales assessed, but there was a large range in size. One or two bones may have come from a foetal whale, suggesting that pregnant females may have been harvested. The two distinct whaling seasons of the Basques, which were historically thought to refer to right whales (summer) and bowheads (fall), may have resulted from sex- and/or age-based segregation and migration of the bowhead population (McLeod et al. 2008).

In summary, while detailed age and sex composition data for the entire harvest series are unavailable, it is apparent that whales of both sexes and all ages were taken. Sex ratios in the Baffin Bay fishery approached 50:50, and the size of whales harvested declined towards the end of the commercial whaling period. The use of steam-powered vessels (chiefly by the Scottish fleet) in the late 1800s allowed whalers to penetrate further into the Canadian Arctic and enter the Prince Regent Inlet nursery grounds, which may have resulted in an increased harvests of calves and juveniles towards the later stages of the fishery. A higher proportion of calves were taken in Hudson Bay, with a higher proportion of subadults taken in Baffin Bay and a similar proportion of adults taken on both grounds. This pattern is possibly due to northwest Hudson Bay being an important historical nursery ground. Basque harvests in Labrador require further study, but limited evidence suggests that mostly adult whales were taken. Early Thule whalers took mostly juvenile and subadult whales (McCartney and Savelle 1985, 1993; Savelle and McCartney 1991, 1994), but the size of whales taken by Inuit hunters after ca. 1500 AD has not been well documented. In Labrador during the late 1700s a variety of age classes were taken, ranging from juveniles to large adults (Taylor 1974, 1988). Inuit hunters in the High Arctic also appear to have at least occasionally taken larger whales (e.g., five large whales in Admiralty Inlet in 1869, Hall 1876).

DATA QUALITY FOR MODELING STUDIES

The harvest data included here are compiled from a variety of sources, and there is considerable variation in the quality and availability of harvest data. For certain nations and eras (e.g., Dutch after 1719, English after 1814) harvests are based on hard data on the number of vessels and whale yield (oil and/or baleen). These harvests can be considered the most accurate and reliable, but yet even with these data there are a number of assumptions and uncertainties. Harvest estimates are based on assumptions of typical whale yield, and the number of whales is estimated based on oil and/or baleen data. In his summary of whale catches, Ross (1979a: 118) was careful to note that "[p]rinted figures tend to possess an air of unassailable reliability. The impressive columns of numbers ...by their smug, self-confident appearance, may suggest a degree of accuracy that is in fact entirely unwarranted".

For many nations and eras, time series data of vessel numbers and whale products obtained are not available. For these harvests it was necessary to employ a number of assumptions that may not be accurate. For population modeling it will be necessary to explore and account for the uncertainty in these estimates. Harvest data was therefore scored for data quality and reliability on a three-point scale as follows:

1 – (Most reliable), harvest data from published peer-reviewed studies with yearly data on harvests (either number of whales or yield in oil and/or baleen) and number of vessels (i.e., CPUE data) if applicable (commercial harvests), with harvests west of Greenland explicitly separated from those on the Spitsbergen grounds. Examples of "reliable" harvest data include those made by American whalers after 1846 (Ross 1979a), Dutch after 1719 (de Jong 1978, Ross 1979a), English after 1814 (Ross 1979a; Sanger unpublished), Scottish after 1750 (Sanger 1985), German harvests after 1719 (de Jong 1978, Ross 1979a), and Inuit harvests in Labrador from 1771-1849 (Taylor 1974, 1988; Brice-Bennett 1978; Reeves et al. 1983) and those during the 1900s after commercial whaling ended (Gaston and Ouellet 1997; Hay et al. 2000; Kapel 1979, 1985; Kapel and Peterson 1982; Mitchell and Reeves 1982; Reeves et al. 1983; Reeves and Heide-Jørgensen 1996;

Richard 2000; Siku Circumpolar News Service 2004; Stewart et al. 1991; J. Peters and A. Kulula pers. comm.).

2 – Some data available on either whale yields or vessel numbers, but not separated into the Davis Strait and Spitsbergen grounds or with no CPUE data. Harvests were assigned to the Davis Strait fishery based on assumptions on effort and harvest efficiency (CPUE) from other nations. Examples of "moderately reliable" harvest data include early English harvests (estimated using vessel and product data from Jackson 1978 and a number of assumptions), French harvests in the 1800s (using data from Du Pasquier 1986 and a number of assumptions), Danish shore-station whaling in West Greenland between 1721 and 1807 (using data from Gad 1973, 1982, and a number of assumptions), and American harvests from Best (1987) (no data on vessel numbers).

3 – (Least reliable), harvests estimated using a variety of disparate data sources and assumptions, and not based on actual time series data of vessel numbers of whale products. The "least reliable" harvest data here include those of the Basques in the Strait of Belle Isle and Gulf of St. Lawrence, all Inuit harvests excluding those noted above, and Danish catches in West Greenland from 1808 to the late 1800s (using assumed average harvests from Vaughn 1984).

Table 8 summarizes the estimated harvests by era and nation and the reliability of the data. The most reliable data (score = 1) result in a total estimated harvest of 31,125 whales between 1719 and 1915. Over half of the estimated total harvests (31,478 to 42,707 whales, depending on Basque harvests) are based on a number of assumptions and are considered the least reliable.

SUMMARY, CONCLUSIONS AND DIRECTIONS FOR FURTHER RESEARCH

The history of bowhead whaling in the waters of eastern Canada and West Greenland is long and varied, and I have attempted to compile all available harvest data. However this compilation was limited mainly to published sources (the exception being some of C. Sanger's British data), and no archival material was examined. There is additional information available in museums and archives (e.g., the logbooks of the Royal Greenland Trade, Eschricht and Reinhardt 1866; Klinowska 1982; Klinowska and Gerslund 1983). However such detailed historical research was beyond the scope of this project, and much painstaking research will be needed to fill gaps in the harvest series, which will never be truly complete. Nonetheless, the harvest data presented here (Figures 2-5, Tables 4, 6, 8) represent an improvement over de Jong (1978) and Ross (1979a), which were previously the most complete harvest series available. Using this revised harvest series will improve estimates of pre-exploitation population size over previous attempts (Mitchell 1977; Mitchell and Reeves 1981; Woodby and Botkin 1993).

The quality of catch reporting varies considerably between different nations and eras. Dutch data are among the most extensive and accurate, however there are differences between the harvest series provided by different sources (de Jong 1978, 1983 vs. Ross 1979a). Similar situations exist for both British (Ross 1979a vs. Sanger unpublished) and German (Ross 1979a vs. de Jong 1983) whaling. The differences are small and mostly reflect varying assumptions about the oil and baleen yield of an average bowhead and differences in deciphering historical documents. In Table 3, the minimum total commercial harvest estimate is based on the source with the highest recorded harvest, with yearly gaps filled in using other sources where appropriate.

For Basque whaling, a complete catch series, or even the rudimentary start of one, is unavailable. The Basque were active in the Strait of Belle Isle and Gulf of St. Lawrence since ca. 1530 AD and the fishery peaked in the mid-1500s (Barkham 1984). The vast majority of harvested whales were bowheads (McLeod et al. 2006; Rastogi et al. 2004). Peak harvests in the range of 300-500 whales per year have been estimated (Aguilar 1986; Barkham 1984; this study). Basque whalers also fished in Davis Strait in the 1700s, at least sporadically, but harvests are unknown. There is no data concerning Dutch Davis Strait whaling prior to 1719 (de Jong 1978, 1983; Ross 1979a). A similar situation exists with German data (de Jong 1983, Ross 1979a), which is not only limited in temporal coverage but also limited to one port (Hamburg). No complete history of Danish whaling at the West Greenland colonies has been written. The summaries of Gad (1973, 1982) and Vaughn (1984) presented here are only an initial step towards establishing a catch history for this phase of whaling.

British harvest data for 1750-1801 are available for Scottish harvests only (Sanger 1985) and after 1814 for both English and Scottish harvests (Ross 1979a, 1993; Sanger unpublished). Data on vessels and whales harvested are also available for Scottish whaling only from 1802-1813 (Sanger, unpublished). Jackson (1978) provides limited data on English harvests from 1750-1800. A number of assumptions resulted in the estimated English whale kill for those years (Table 2). This is a slight improvement over previous compilations but it is no substitute for detailed historical research. Another source of British whale products was trade between Inuit and the Hudson's Bay Company. Barr (1994) summarized data for 1737-1800, which included the baleen from ca. 115 whales. While these data assist in providing a more complete harvest series, they again do not summarize the entire trade.

Ross (1979a) provides American Davis Strait whaling after 1846 and in Hudson Bay from 1860. However this series is missing harvests from the first American whaling trips to Davis Strait in the 1700s. Best (1987) also provides an estimate of 248-291 bowheads taken by American whalers from 1815-1819. This occurred previous to the American expansion into the Pacific grounds, so these whales were likely harvested in Davis Strait by right and sperm whaling vessels. After the Basques left the Strait of Belle Isle and Gulf of St. Lawrence Canadian colonists conducted sporadic whaling there. At least some bowheads were taken (Clark 1887) but the harvest is again unknown.

Inuit throughout eastern Canada and West Greenland have harvested bowhead whales for centuries. Knowledge of the total Inuit harvest will always be elusive, but there are some data. The total estimated Inuit harvest from 1000-2005 AD is 24,247 whales (Figure 3, Table 6). The majority (65%) were harvested prior to the start of commercial whaling ca. 1530 AD. Low numbers were harvested after the cessation of commercial whaling in the early 1900s, but these are minimum estimates and more whaling likely took place (Mitchell and Reeves 1982).

An estimated harvest of almost 25,000 animals may sound unreasonably high; however this took place over ca. 1000 years and never exceeded 36 whales per year (during the peak of the classic Thule period). In most years harvests were considerably lower, and even during peak years Inuit harvests paled in comparison to those made by commercial whalers (Figure 4). Inuit harvests alone would not have negatively impacted a healthy bowhead population and would have remained sustainable if commercial whalers had not reduced the species to such low numbers. With an annual growth rate of 3-4% (George et

al. 2004), a pristine population of 10,000 whales (likely an underestimate, Woodby and Botkin 1993) would produce far more calves per year than the number of young whales taken for subsistence purposes. Even if the harvest series significantly underestimated true harvest levels, there would likely have been little effect on bowhead populations in the absence of commercial harvests.

Inuit harvests, as summarized in Figure 3, show little year to year variation, except for Labrador harvests during the early contact period (when Moravian missionaries kept detailed records). The estimated harvests for the remaining regions and time periods (and also for Basque whaling) are based on estimated average yearly harvests and ignore the variability that undoubtedly occurred. Data to incorporate this variability do not exist, although climatic data could conceivably be used as a proxy to incorporate some estimate of variability around the mean values reported here.

The Inuit harvest series is based on limited data and a number of assumptions which will be extremely hard to test. One method which may be used to better quantify the importance of bowhead whales over time is the use of stable isotopes. Coltrain et al. (2004) used stable isotope signatures of skeletal remains to measure the importance of different species to modified Thule whalers in Hudson Bay. Bowhead whales accounted for approximately 12% of the total dietary intake. Without similar data from other regions and time periods it is difficult to convert this to an estimate of the number of whales used or how the importance of bowhead whales changed over time. Analyses of isotopic signatures of classic Thule remains, perhaps from Somerset Island, would assist in quantifying the importance of bowhead whales over time. Another pertinent research avenue would be examination of skeletal remains from Labrador Inuit. Analysis of remains from 1500 to the mid-1800s could be used in conjunction with the detailed harvest series in the Moravian mission documents (Taylor 1974, 1988) to better assess the importance of bowhead whales over time. However an assessment such as this still would not incorporate the likely importance of bowhead whale oil as fuel.

Overall, the combined commercial and Inuit harvests in eastern Canada and West Greenland since 1530 AD was estimated as 71,590 whales (Figure 5, Tables 3, 6). The manuscript includes little information on the numbers of vessels and/or catch per vessel. Catch per unit effort (CPUE) data are available for some whaling nations and/or periods, but not all. Those with CPUE data are considered the most reliable (see Table 8). This harvest series can now be used with a population model to improve past estimates of pre-exploitation population size. All whale harvests reported here are landed whales only, with no accounting for struck and lost whales (with the exception of recent Inuit harvests as discussed above). During population modelling it will be necessary to explore various assumptions regarding struck and loss rates, and rates of 15-20% used previously (Mitchell 1977) may be too conservative. Overall, the use of this expanded harvest series, and more detailed modelling techniques, will provide more accurate estimates of pre-whaling population size and improve conservation and recovery planning for eastern Arctic bowhead whales.

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Table 1. Estimated Basque whale harvest (all species) in the Strait of Belle Isle and Gulf of St. Lawrence assuming the proportion of written references (Aguilar, 1986) represents actual whaling effort, with various assumptions as to the total number of whaling vessels during the peak harvest period 1551-1575. A small proportion of written references (ca. 3%) were dated pre-1530. Genetic data (McLeod et al. 2008) indicate that nearly all (ca. 90%) whales were bowheads.

Period	Percentage of written references[1]	Harvest/year with different numbers of vessels during peak (1551-1575)		
		20	25	30
1530-1550	20.5	219	273	328
1551-1575 (peak)	22.5	240	300	360
1576-1600	19.5	208	260	312
1601-1625	10	107	133	160
1626-1650	7	75	93	112
1651-1675	11	117	147	176
1676-1700	4.5	48	60	72
1701-1713	2	38	48	57
Total estimated harvest		24,968	31,182	37,429

[1] from Aguilar (1986), Figure 4

Table 2. English Davis Strait whaling efforts from 1750-1800 estimated using vessel and oil data from Jackson (1978). Oil yield converted to number of whales using Jenkins (1971) and Aguilar (1986), English whale harvest determined by subtracting Scottish harvests from Sanger (1985), and proportion of total vessels and total whale harvest in Davis Strait estimated using Scottish whaling effort (Sanger 1985).

Year	English "Greenland fishery"		English in West Greenland			Notes
	Vessels	Whales	Vessels	Whales	Whales/vessel	
1750	19	26	--	--	--	Reportedly 20 English vessels in Davis Strait (Proulx 1986 – but not a reliable source, Barkham 1994)
1751	23	32	4	32	8.00	
1752	30	16	3	2	0.67	
1753	35	2	3	1	0.33	
1754	52	40	4	0	0.00	
1755 to 1786	1852	2,867	0	0		No Scottish vessels in Davis Strait between 1755 and 1786 (Sanger 1985). An estimated 1852 English voyages caught 2867 whales between 1755 and 1786 but none were assigned to West Greenland.
1787	217	609	7	34	4.86	
1788	222	426	51	144	2.82	Reportedly 90 English whalers in West Greenland waters (Gad 1982)
1789	151	309	62	184	2.97	
1790	103	244	47	72	1.53	
1791	93	195	33	109	3.30	
1792	87	157	53	27	0.51	
1793	73	210	42	102	2.43	
1794	53	175	14	92	6.57	
1795	40	177	12	62	5.17	
1796	44	256	10	73	7.30	
1797	57	328	17	66	3.88	
1798	59	333	24	114	4.75	
1799	60	338	12	96	8.00	
1800	54	318	16	88	5.50	
Total			414	1,298		

Table 3. Summary of Euroamerican bowhead whale harvests, by nation (see text for further details).

Nation	Start	End date	Estimated bowhead harvest
Norse settlers, West Greenland	1150	Pre-1500	unknown
Basque	1530	1713	22,454-33,683[1]
	1714	1800s	unknown
Dutch	1600s	1718	unknown
	1719	1826	7,699
British	1750	1911	23,250[2]
German	1600s	1718	unknown
	1719	1792	332
Danish-Norwegian	1600s	1720	unknown
	1721	1890	1,969
French	1719	1837	608
American	1700s	1700s	unknown
	1815	1915	1,195
Canadian	????	????	unknown
Total estimated harvest[3]			57,507-68,736 (63,128)

[1] Range of values depending on assumptions of vessels per year during peak (1551-1575) (see Table 1).

[2] Includes 115 whales secured by Hudson's Bay Company (HBC) through trade with Hudson Strait Inuit and six whales taken by HBC whalers in the mid-1700s, but excludes English Davis Strait harvests in the mid-1700s and 1801-1814.

[3] Range of values depending on assumed number of Basque vessels, value in parentheses assumes a peak Basque effort of 25 vessels per year (midpoint of Table 1).

Table 4. Estimated bowhead whale use by classic Thule (ca. 1000-1300 AD) in the central and eastern Canadian Arctic (columns 1-4 from McCartney (1979) as summarized by Stoker and Krupnik (1993)).

Region	No. houses	Avg. whales per house	Min. no. whales	Median total whales	Whales per year	Nunavut region
Somerset Island	183	10-15	1,830-2,745	2,288	8	Qikiqtaaluk
Boothia Peninsula	50	4-5	200-250	225	1	Kitikmeot
Admiralty Inlet	93	3	279	279	1	Qikiqtaaluk
Navy Board-Pond inlets	161	3	483	483	2	Qikiqtaaluk
Clyde area	140	2-3	280-420	350	2	Qikiqtaaluk
Broughton area	303	1	303	303	1	Qikiqtaaluk
Cumberland Sound	389	3	1,167	1,167	4	Qikiqtaaluk
Frobisher Bay-Hudson Strait-Foxe Peninsula	155	2-3	310-465	388	2	Qikiqtaaluk
Western H. Bay-Repulse Bay-Southampton Island	300	1	300	300	1	Kivalliq
Western Melville Pen. and adj. islands	103	3	309	309	1	Qikiqtaaluk
Ellesmere-Northern Devon islands	186	2-3	372-558	465	2	Qikiqtaaluk
Lancaster Sound-Barrow Strait	131	1-2	131-262	197	1	Qikiqtaaluk

Table 5. Approximate dates of the "baleen period" as defined by Schledermann (1979).

Site	Approximate time period (AD)
Naujan (Repulse Bay)	1000-1100 to 1400
Cumberland Sound	1250 to 1650
Labrador	1500 to 1700
Comer's Midden (Northwest Greenland)	1200-1300 to 1550
Sermermiut (Disko Bay, Greenland)	1200-1300 to 1650

Table 6. Summary of estimated Thule/Inuit bowhead whale harvests in eastern Canada and West Greenland between 1000 and 2005 AD.

Pre-1500			
Location	Period (AD)	Yearly harvest	Total whales
Repulse Bay (Naujan)	1000-1400	1	401
Cumberland Sound	1250-1500	4	1,004
Remainder of Canadian Arctic	1000-1500	21	10,521
West Greenland	1200-1500	10	3,010
Total			14,936
Peak harvest	1250-1400	36	

1501 - "historic"			
Location	Period (AD)	Yearly harvest	Total whales
Western Baffin Island	1501-1650	11	1,650
Labrador	1501-1700	5	1,000
Hudson Bay/Nunavik	1501-1700	5	1,000
Northwest Greenland	1501-1550	5	250
Southwest Greenland	1501-1650	5	750
Total			4,650
Peak harvest	1501-1550	31	

"historic" period			
Location	Period (AD)	Yearly harvest	Total whales
Cumberland Sound	1651-1860	10	2,100
Northern Hudson Strait (southern Baffin Island)	1651-1860	3	630
Southwest Hudson Bay (Marble Island south)	1701-1860	1	160
Repulse Bay (and Foxe Basin)	1701-1860	2	320
Nunavik	1701-1860	2	320
Labrador	1701-1770	5	350
	1771-1849	NA	143*
West Greenland	1651-1721	5	355
	1722-1770	3	147
	1771-1900	1	130
Total			4,655
Peak harvests	1793	34	
	1781	32	
	1651-1721	28	

post-commercial whaling period			
Location	Period (AD)	Yearly harvest	Total whales
All regions	1918-2005	NA	56**

Total harvest 1000-2005 AD	24,247
Harvest 1530-2005 AD	8,462

* includes 36 struck/lost
** includes 14 struck/lost

Table 7. Numbers of sail and steam powered vessels in British Davis Strait and East Greenland whaling 1865-1876, with total whale harvest and average number of whales per vessel, by vessel type (data from Clark 1887).

	Number of vessels		Number of whales		Catch per vessel	
Year	Sail	Steam	Sail	Steam	Sail	Steam
1865	15	11	5	62	0.3	5.6
1866	13	15	42	37	3.2	2.5
1867	11	30	16	8	1.5	0.3
1868	12	18	23	111	1.9	6.2
1869	10	16	8	14	0.8	0.9
1870	8	14	18	61	2.3	4.4
1871	6	15	11	141	1.8	9.4
1872	5	17	9	125	1.8	7.4
1873	4	18	12	160	3.0	8.9
1874	3	16	0	190	0.0	11.9
1875	2	18	13	85	6.5	4.7
1876	3	17	5	77	1.7	4.5

Table 8. Summary of commercial and Inuit subsistence harvests of bowhead whales in eastern Canada and West Greenland since 1530 AD, with estimates of data quality.

Nation	Era	Harvest	Data	Source(s)
Basque	1530-1713	22,454-33,683	3	Numerous assumptions, see text
Dutch	1719-1826	7,699	1	de Jong 1983; Ross 1979a
Scottish	1750-1813	1,519	1	Sanger 1985, unpublished
English	1750-1800	1,298	2	Jackson 1978 and assumptions
English (HBC)	1767-1772	6	1	Ross 1979a
British (Scottish and English)	1814-1911	20,312	1	Ross 1979a; Sanger unpublished
English (HBC trade)	1737-1800	115	1	Barr 1994
German	1719-1792	332	1	de Jong 1983; Ross 1979a
Danish-Norwegian	1721-1776	358	2	Gad 1973
	1777-1807	850	2	Gad 1982
	1808-1890	761	3	Vaughn 1984 and assumptions
French	1719-1837	608	2	Du Pasquier 1986 and assumptions
American	1815-1819	250	2	Best 1987
	1846-1915	945	1	Ross 1979a
Inuit (excluding Labrador 1771-1849)	1530-1917	8,263	3	Numerous assumptions, see text
Labrador Inuit	1771-1849	143	1	Taylor 1974, 1988; Brice-Bennett 1978; Reeves et al. 1983
Inuit post-commercial whaling	1918-2005	56	1	Gaston and Ouellet 1997; Hay et al. 2000; Kapel 1979, 1985; Kapel and Peterson 1982; Mitchell and Reeves 1982; Reeves et al. 1983; Reeves and Heide-Jørgensen 1996; Richard 2000; Siku Circumpolar News Service 2004; Stewart et al. 1991, J. Peters and A. Kulula pers. comm.

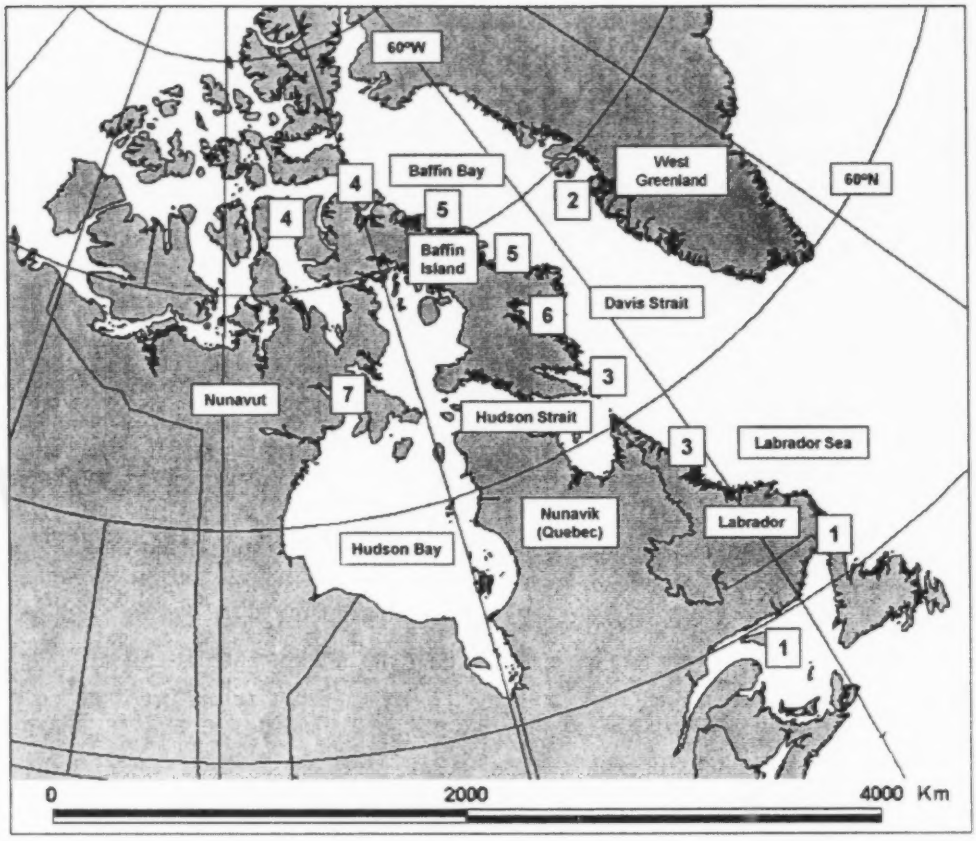

Figure 1. Map of the eastern Arctic showing the seven main whaling grounds: 1) Strait of Belle Isle/Gulf of St. Lawrence; 2) the West Greenland coast, or "east side" grounds; 3) the spring "south-west fishing" grounds, including the northeast coast of Labrador, the mouth of Hudson Strait, and southeast Baffin Island; 4) the summer "west water" grounds, including Pond Inlet, the Lancaster Sound region, and Prince Regent Inlet; 5) the autumn "rock-nosing" grounds along the entire east coast of Baffin Island; 6) Cumberland Sound, a spring and fall fishery; and 7) northwestern Hudson Bay.

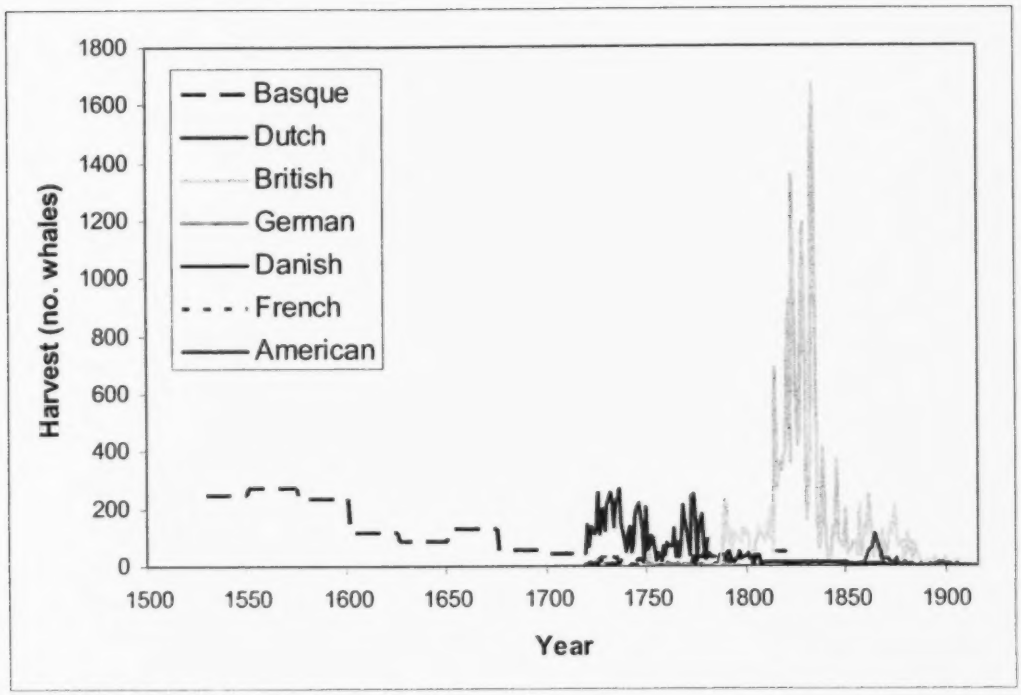

Figure 2. Estimated commercial harvest of bowhead whales in eastern Canada and West Greenland, 1530-1915 AD, by nation. The Basque harvest is based on an assumed peak of 25 vessels per year.

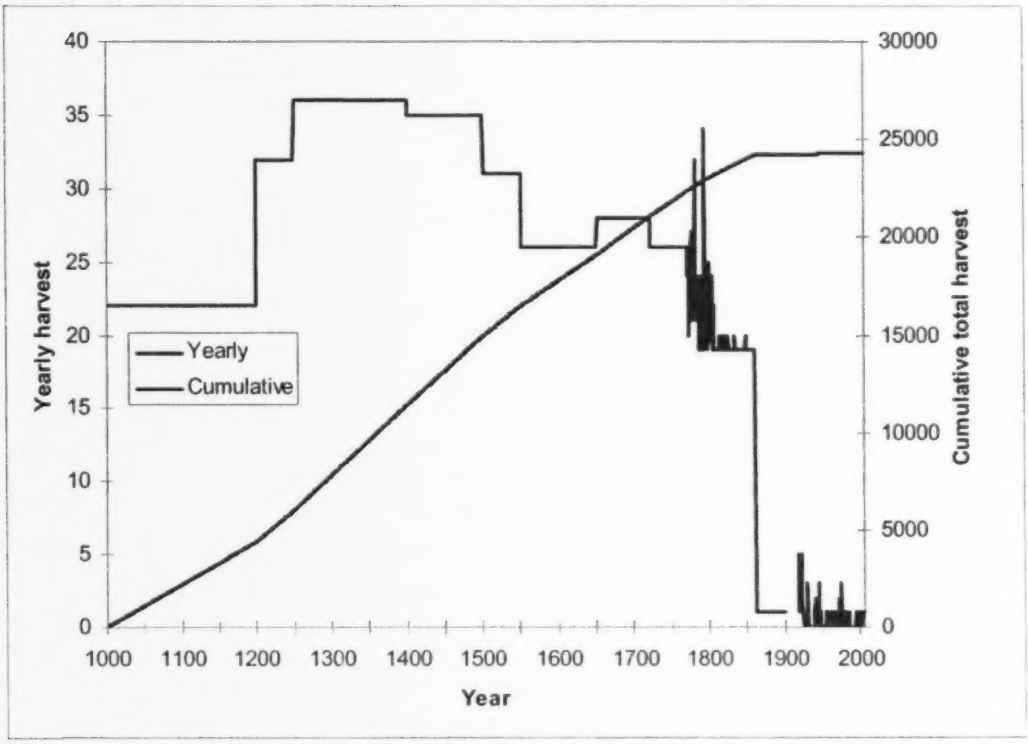

Figure 3. Estimated yearly and cumulative Inuit harvests of bowhead whales in the eastern Canadian Arctic and West Greenland between 1000 and 2005 AD. Pre-1500 harvests represent the classic Thule culture, and the majority of Inuit harvests occurred during this time, prior to the establishment of commercial whaling ca. 1530 AD.

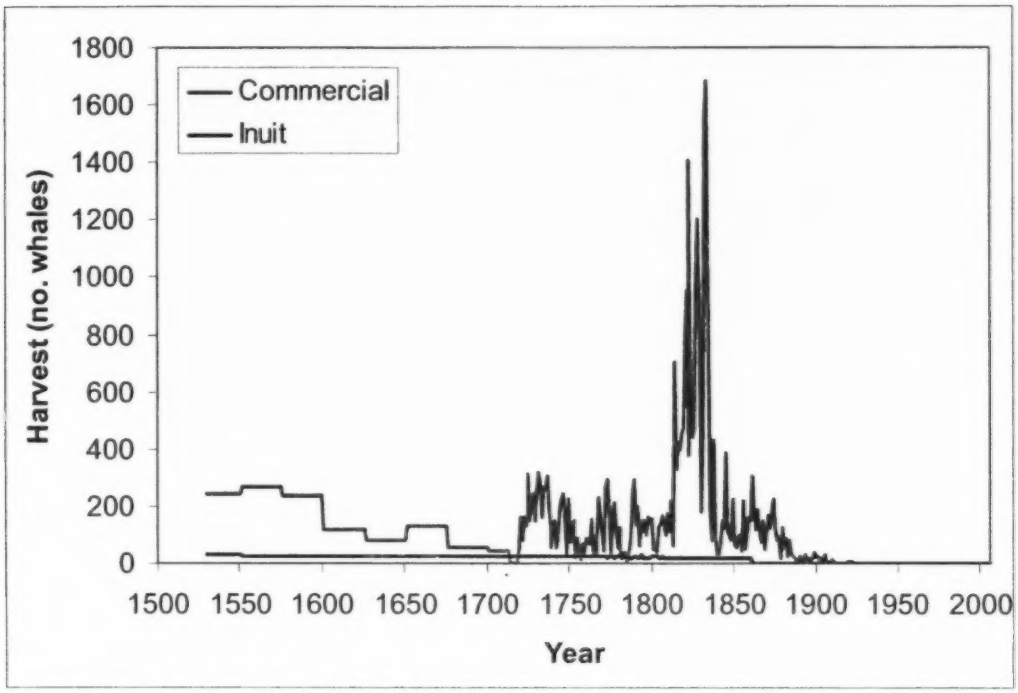

Figure 4. Comparison of commercial and Inuit subsistence harvest levels of bowhead whales in the eastern Arctic, 1530-2005 AD. Commercial harvests assume peak Basque whaling effort of 25 vessels per year.

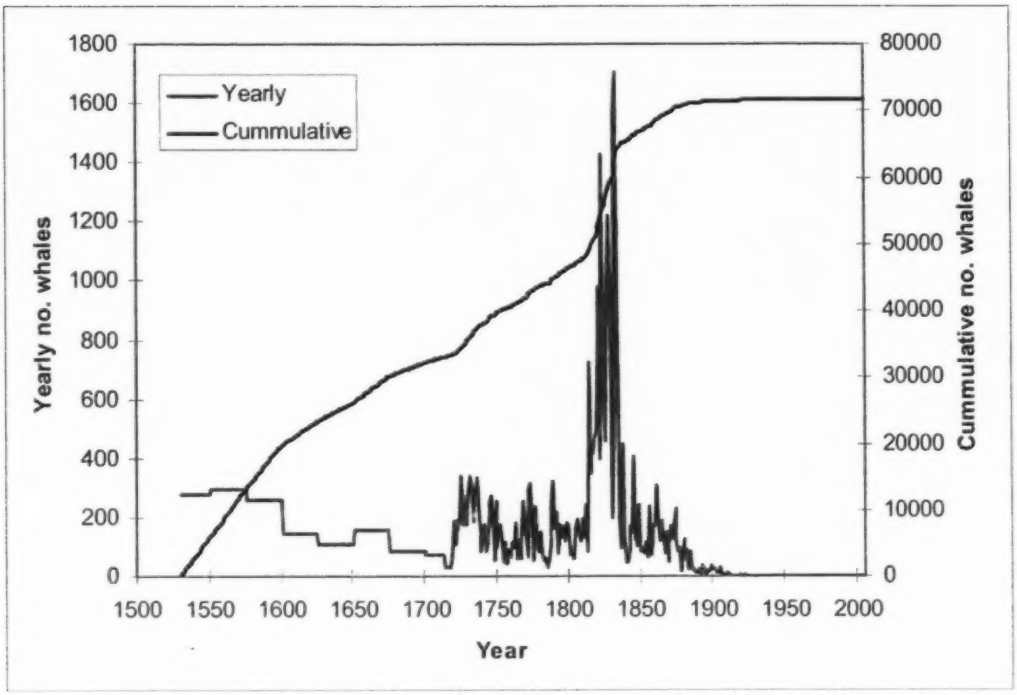

Figure 5. Total yearly and cumulative harvest of bowhead whales in eastern Canada and West Greenland, 1530-2005 AD, combining both commercial and Inuit harvests (25 Basque vessels per year during peak).

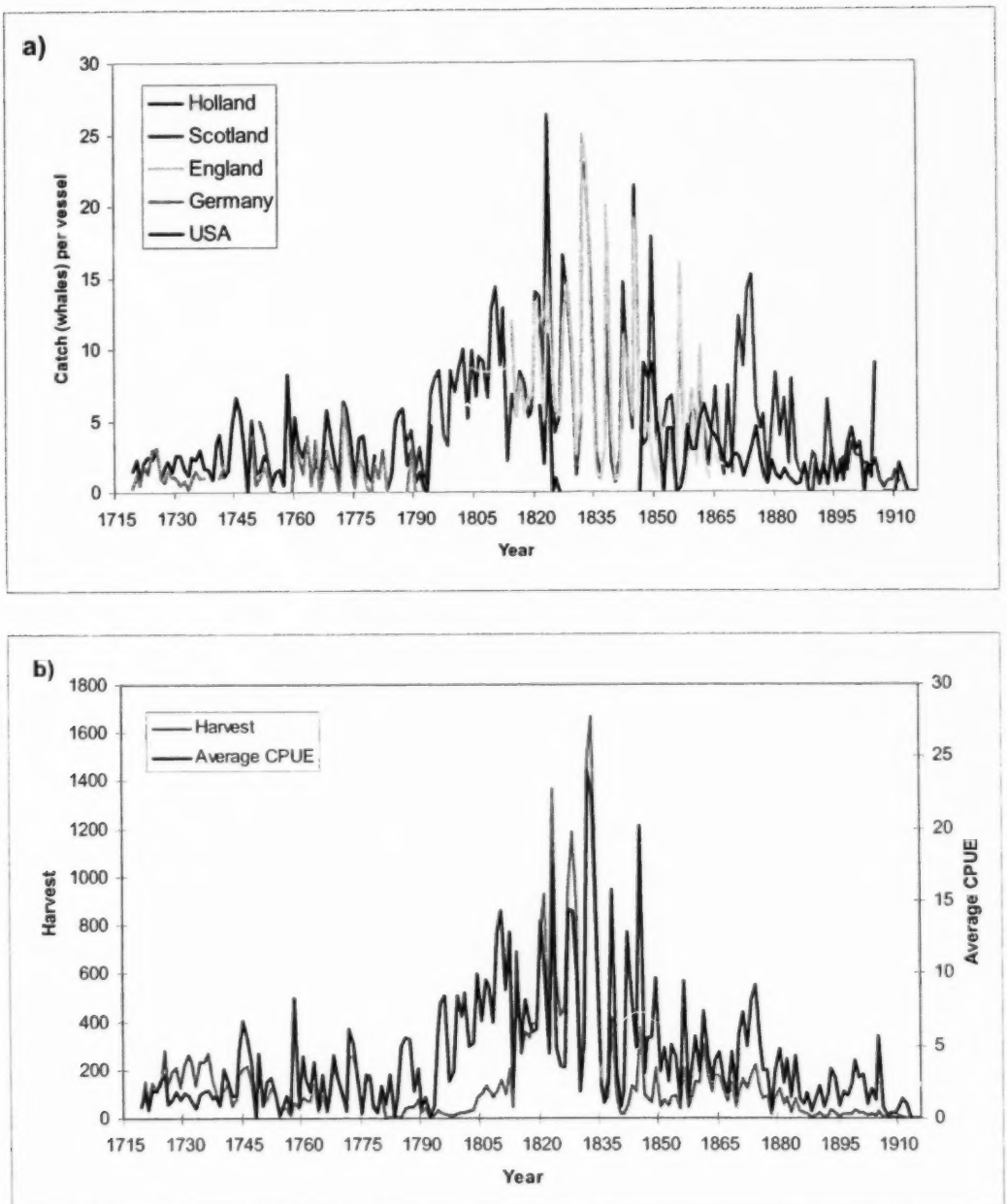

Figure 6. Catch per unit effort (CPUE), measured as the number of whales per vessel (or "ship-season) for a) five commercial whaling nations, and b) for all five nations combined as compared to total whale harvest.